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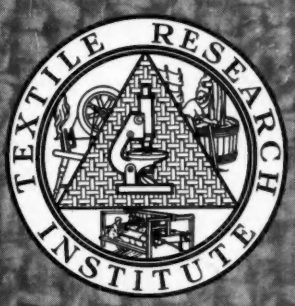

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Rayon Reports

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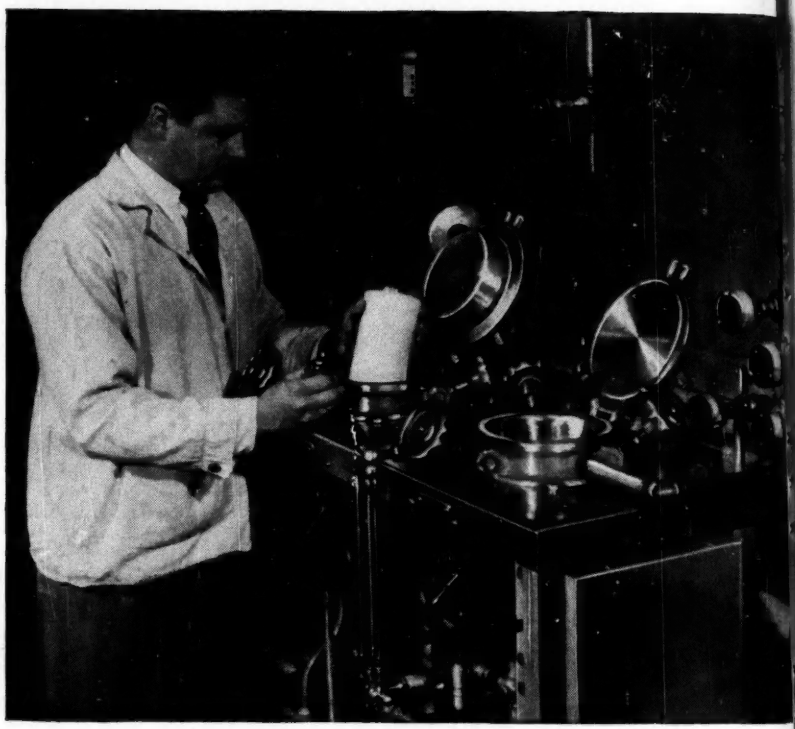

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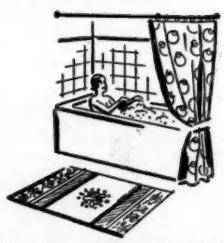

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TEXTILE RESEARCH JOURNAL

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Interpretation of Tests for Resistance to Abrasion of Textiles*

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Abstract

The resistance to abrasion of sixteen cotton fabrics, which varied systematically in warp and filling yarn number and in ends and picks, was determined with the Schiefer abrasion testing machine, using No. 600A silicon carbide waterproof abrasive paper as the abradant and a total load of 2 lbs. on the specimen in one testing procedure, and a blade abradant and a total load of 20 lbs. on the specimen in a second testing procedure. The rate of abrasion in the first testing procedure was over ten times as great as that in the second. The results for the testing procedures could be represented very well by the following equations:

$$\log R = a + bW + cF + dE + eP,$$

$$\log R = \log Ro + a \log W + b \log F + c \log E + d \log P,$$

where R is the number of rotations of the abradant, W is the warp yarn number, F is the filling yarn number, E is the ends per inch, P is the picks per inch, and the other quantities are constants. It was found that the rankings of the sixteen fabrics were different for the two testing procedures. This difference is due mainly to the fact that a given change in any one construction factor does not always result in quantitatively comparable changes in the resistance to abrasion obtained by the two procedures. This sort of difference is obtained, and should be expected, when comparing results of highly accelerated laboratory abrasion tests with results of comparatively slow rates of wear in service or performance tests. The resistance to abrasion of eight other fabrics of intermediate constructions obtained with each abradant agreed very well with the values computed by using the above two equations.

Introduction

Evaluation of the resistance to abrasion of textiles is receiving increased consideration, and methods of testing have been published for a number of testing machines [1, 2, 3, 4, 5, 6, 13]. It is hoped that this work will lead to increased knowledge and greater appreciation of the value and significance of the results of abrasion tests—for example, to a clearer understanding and interpretation of the results obtained in relation to specific factors, such as kind of fiber, yarn and fabric construction, finishing treatment, and chemical modification of fibers. The true picture of the relationship of abrasion results to the performance in use of textiles also can be expected to evolve slowly as more adequate data become available as a result of carefully planned experiments in laboratory and service wear testing. A very

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critical factor in the establishment of this relationship is the influence of the rate and type of abrasion involved in such tests [2, 3, 5, 6].

The purposes of the work reported herein are: (1) to indicate the importance of the nature of the abradant, of the type of abrasion produced, of the rate of abrasion, and of the constancy of the abradant on the results of abrasion tests; (2) to determine the effects of specific yarn and fabric construction factors on abrasion-resistance; (3) to obtain analytical expressions relating the effects of these construction factors to the resistance to abrasion; (4) to investigate the effect of two very different rates of abrasion on the rank correlations of abrasion-resistance of fabrics in the same series; and (5) to give a critical discussion of the results and their significance. The results were obtained for the most part with the Schiefer abrasion testing machine [9, 10], using two different types of abradants and rates of abrasion, and testing sixteen cotton fabrics of the same weave in which the ends (warp yarns per inch), picks (filling yarns per inch), warp yarn number, and filling yarn number were varied systematically. References are also made to results obtained with other abrasion testers and on very different types of materials.

Importance of Type of Abradant and Abrasive Action

The abrasive paper type of abradant, such as emery paper, sandpaper, and silicon carbide waterproof paper, is used extensively in textile testing. A schematic cross section of a frequently used abrasive paper and a cotton fabric, both drawn to relatively the same scale, is shown in Figure 1. The dimensions of the abrasive particles are of about the same order of magnitude as the thickness and width dimensions of cotton fibers. The type of abrasion is a cutting action, often of a whole fiber upon first contact, and the rate of abrasion is very fast. Obviously, under these conditions an abradant particle cannot discriminate between fibers of different kinds, and is not sensitive to whether the fiber is untreated, treated with a special finish, or chemically modified. This type of abradant is not effective for evaluating the effect of finishing and chemical treatments on the abrasion-resistance of textiles.

In tests made with this type of abradant, a new piece of abrasive paper was used for each textile specimen tested. The abrasive action of each piece of abrasive paper decreases very rapidly during each test [10]; this is an undesirable characteristic of this type of abradant. Obviously, a fabric of low resistance to abrasion (short duration of test) is very highly penalized with respect to one of high resistance to abrasion. The danger of thus misinterpreting the experimental results can be greatly reduced by basing comparisons on the logarithms of the numbers of rotations rather than on the numbers themselves.

A spring-steel blade abradant [9, 10] was developed in an effort to overcome the deficiencies of the abrasive paper type of abradant. Abrasion with the blade abradant is not a cutting action, but, rather, consists of the removal of small particles of the fiber ranging in size from 100 to 200 Å. [7, 11, 12, 14]. In Figure 2 are shown two monofilaments of polyethylene which have been uniformly and deeply abraded along a short length by this process. The

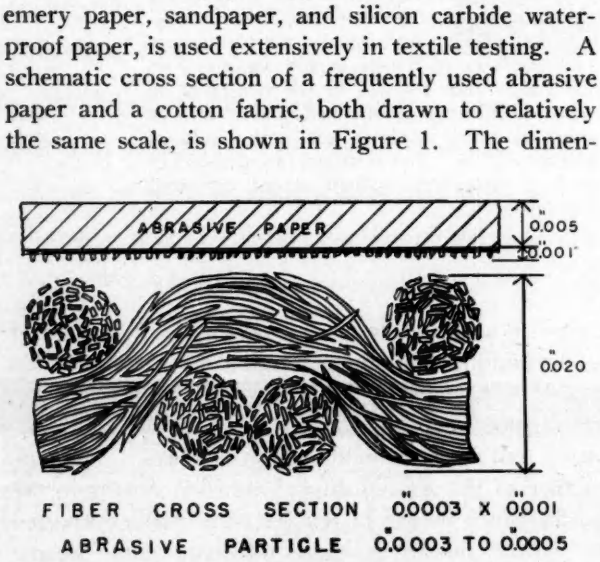

FIG. 1. *Schematic cross section of cotton fabric and abrasive paper.*

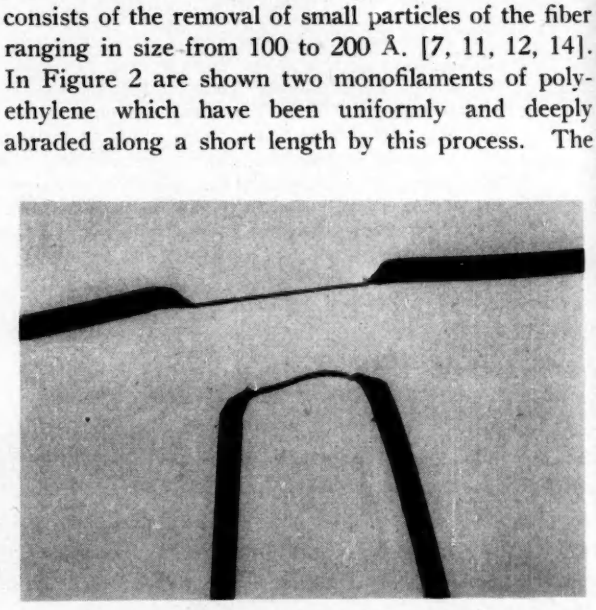

FIG. 2. *Abraded portions of polyethylene monofilament yarn.*

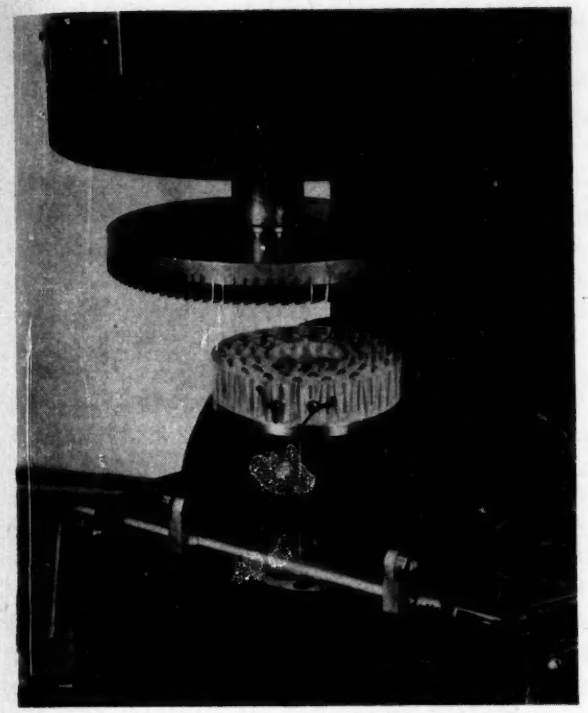

FIG. 3. *Clamp for testing resistance to abrasion of yarns.*

yarns were fastened in the holder shown in Figure 3 during the abrasion test. Abrasive wear with the blade type of abradant is extremely sensitive to kind of fiber, finishing treatment, chemical modification of fiber, and yarn and fabric construction. The rate of abrasion is very slow compared with the abrasive paper type of abradant.

The abrasive action of blade abradants remains remarkably constant for long periods of use—for example, for several million rotations of abrasion. The data of Table I illustrate this feature very well. A blade abradant was used to test six replicas of sixteen cotton fabrics. There was no systematic change in the total number of rotations of abrasion required for each replica. The order in which the fabrics were tested in each replica was changed systematically. A variance analysis showed no systematic change in the abradant in nearly two million rotations. The small variations shown in Table I for the six test sets can be attributed entirely to the variability among the fabric specimens.

The results of similar tests are shown in Table I for the abrasive paper. The variation among the first three test sets is about the same as among the last three, and can be attributed to the variability among the fabric specimens. There was a systematic difference, however, between the first three and the last three sets, which is unquestionably associated with the two different sources of the abrasive paper. As a matter of fact, it is quite possible that a similar or even greater difference would be found between two different deliveries of abrasive paper from the same manufacturer. One manufacturer of abrasive papers stated that it is very difficult to measure the abrasive action of abrasive paper, and that a more satisfactory evaluation method is badly needed for production control.

TABLE I. UNIFORMITY AND CONSTANCY OF ABRADANTS

Abradant	Test set	No. of rotations, R	Log R
Blade	I	317,000	5.501
Blade	II	360,000	5.556
Blade	III	347,000	5.400
Blade	IV	305,000	5.484
Blade	V	323,000	5.509
Blade	VI	309,000	5.490
Abrasive paper			
A	I	6,460	3.810
A	II	7,320	3.865
A	III	7,000	3.845
B	IV	7,950	3.900
B	V	8,060	3.906
B	VI	7,390	3.869

Although the blade abradant has several advantages, it should be mentioned that in tests on some wool fabrics the abradant became coated with small particles of wool and the abrasive action increased tenfold in a matter of only a few minutes [10, 11]. In another experiment the abradant became plated with zinc in a wet abrasion test of a material which had been treated with a zinc compound. This was accompanied by a great increase in the abrasive action of the abradant.

Making blade abradants that give the same abrasive action has received considerable attention and presents a difficult problem. Progress has been made, however, and the problem is certainly not hopeless.

Effects of Specific Construction Factors on Resistance to Abrasion

Sixteen cotton fabrics were chosen for a study of the effect of four construction factors on the resistance to abrasion. The ends, picks, warp yarn number, and filling yarn number of these fabrics

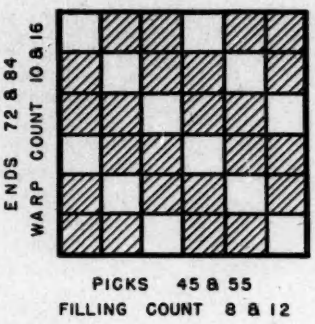

FIG. 4. *Cloth pattern and fabric construction details.*

were varied systematically one at a time. The weave pattern of these fabrics and the nominal values of the four construction factors are indicated in Figure 4. These sixteen fabrics were selected for test from a much larger series which was obtained from the Philadelphia Quartermaster Depot. They were selected because they formed a symmetrical group for six test sets of a statistical experiment for variance analyses and also for deriving functional relationships showing the effect of each construction factor on the resistance to abrasion.

The sixteen cotton fabrics were tested for resistance to abrasion with the Schiefer machine using two different testing procedures. In one, a blade abradant was used. The total load of the abradant on a circular abraded specimen $1\frac{1}{4}$ in. in diameter was 20 lbs. The clamp holding the specimen is suspended freely on the specimen over this area and exerts a constant radial tension on it. This area was abraded until it could no longer support the clamp. As the clamp dropped, it actuated a microswitch which stopped the machine automatically. A counter indicated the number of rotations, R, required for the test of each specimen. Only one specimen of each fabric was abraded on the face side to complete a test set. Then the next test set was similarly completed, and so on, for the six test sets. The order of testing was different for each test set as prescribed in the statistical experiment. In the other testing procedure, pieces of No. 600A silicon carbide abrasive paper were used as the abradant. A new piece was used for each specimen. The total load of the abradant on a circular abraded specimen $1\frac{1}{4}$ in. in diameter was 2 lbs. Otherwise, the testing procedure was the same as that for the blade abradant.

Table II gives the average number of rotations and standard error for the tests of each fabric with the abrasive paper. The two extreme fabrics, which differed in weight by a ratio of about one to two, differed in abrasion rotations by a ratio of about one to eight and in standard error about one to ten. Since the abrasive action of this abradant decreased rapidly during a test, these ratios are definitely too large and may be misleading. Nevertheless, the effects of the construction factors on the number of rotations required for destruction is shown very strikingly.

Table III gives the average number of rotations and standard error for the tests of each fabric with the blade abradant. The two extreme fabrics differed in abrasion rotations by a ratio of about one to thirty-two and in standard error about one to forty-five. These ratios are much greater than those obtained for the abrasive paper, although there was no change indicated in the abrasive action of the blade abradant. If there had been no change in the abrasive paper, the difference in the respective ratios between the two extreme fabrics for the two abradants would have been even much greater. The

TABLE II. ABRASION-RESISTANCE OF COTTON FABRICS USING NO. 600A SILICON CARBIDE WATERPROOF PAPER ABRADANT (AVERAGE NUMBER OF ROTATIONS, R_2, AND STANDARD ERROR)

Fabric construction			Filling cotton number 8		Filling cotton number 12	
			Picks 55	Picks 45	Picks 55	Picks 45
Warp cotton number 10	Ends 84		1166 ± 52	668 ± 75	1052 ± 81	518 ± 28
	Ends 72		749 ± 80	443 ± 12	513 ± 29	360 ± 14
Warp cotton number 16	Ends 84		414 ± 25	232 ± 9	297 ± 18	194 ± 6
	Ends 72		255 ± 7	202 ± 11	158 ± 3	142 ± 5

TABLE III. ABRASION-RESISTANCE OF COTTON FABRICS USING BLADE ABRADANT (AVERAGE NUMBER OF ROTATIONS, R_1, AND STANDARD ERROR)

Fabric construction			Filling cotton number 8		Filling cotton number 12	
			Picks 55	Picks 45	Picks 55	Picks 45
Warp cotton number 10	Ends 84		64,600 ± 5,900	14,500 ± 600	34,400 ± 2,600	11,200 ± 900
	Ends 72		41,500 ± 3,700	11,300 ± 800	28,300 ± 2,700	6,200 ± 700
Warp cotton number 16	Ends 84		14,900 ± 2,500	4,300 ± 160	11,800 ± 750	4,400 ± 210
	Ends 72		61,300 ± 5,300	5,900 ± 430	10,200 ± 830	2,000 ± 130

blade abradant, therefore, appears to be much more selective for evaluation of the effects of the construction factors on the resistance to abrasion. However, if the nominal changes in the construction factors produce such large effects, the normal variations inherent in manufacturing such fabrics [3] should produce comparably large variations in the test results among the specimens of each fabric. This was actually the case. In other words, because of the inherent variations in ends, picks, warp yarn number, and filling yarn number, the more sensitive test with regard to the systematic changes in these factors also magnifies similarly the effect of normal variations of these factors from specimen to specimen. The more sensitive test method apparently, then, has no advantage over the less sensitive method, except to indicate more strikingly that the fabrics were not as uniform as desired for this type of research study. This is especially true for two of the sixteen fabrics. It is obvious that these two fabrics differed in some other factor from the other fourteen fabrics, which affected the abrasion value very greatly and consistently for all the specimens of these two fabrics. A difference in yarn sizing is suspected of being the cause, although this difference was not positively established.

Since the standard error in both testing procedures varied so much, approximately in direct proportion to the number of rotations of abrasion, it is obvious that these numbers have little value for statistical studies and for deriving functional relationships between the construction factors and the rotations of abrasion. All the rotation values were therefore changed to their logarithmic values.

The average logarithm of the rotation values and the standard error are shown in Table IV for each fabric when tested with the abrasive paper. The standard error remains fairly constant and independent of the magnitude of the logarithmic values. Statistical treatments of these values are believed to be valid. A difference greater than 0.070 between any two values of log R_2 is considered significant.

TABLE IV. ABRASION-RESISTANCE OF COTTON FABRICS USING NO. 600A SILICON CARBIDE WATERPROOF PAPER ABRADANT (AVERAGE LOG R_2 AND STANDARD ERROR)

Fabric construction			Filling cotton number 8		Filling cotton number 12	
			Picks 55	Picks 45	Picks 55	Picks 45
Warp cotton number 10	Ends 84		3.065 ± .021	2.807 ± .067	3.015 ± .038	2.711 ± .026
	Ends 72		2.863 ± .049	2.656 ± .020	2.707 ± .027	2.556 ± .018
Warp cotton number 16	Ends 84		2.613 ± .030	2.363 ± .019	2.469 ± .028	2.286 ± .005
	Ends 72		2.405 ± .014	2.301 ± .028	2.198 ± .009	2.149 ± .017

A difference greater than 0.070 between any two values of log R_2 is considered significant.

TABLE V. ABRASION-RESISTANCE OF COTTON FABRICS USING BLADE ABRADANT (AVERAGE LOG R_1 AND STANDARD ERROR)

Fabric construction			Filling cotton number 8, Picks 55	Filling cotton number 8, Picks 45	Filling cotton number 12, Picks 55	Filling cotton number 12, Picks 45
Warp cotton number 10	Ends 84		4.805 ± .040	4.159 ± .023	4.530 ± .038	4.043 ± .039
Warp cotton number 10	Ends 72		4.610 ± .040	4.049 ± .031	4.444 ± .043	3.781 ± .054
Warp cotton number 16	Ends 84		4.144 ± .082	3.637 ± .018	4.068 ± .028	3.639 ± .024
Warp cotton number 16	Ends 72		4.779 ± .043	3.768 ± .034	4.002 ± .040	3.290 ± .032

A difference greater than 0.100 between any two values of log R_1 is considered significant.

The average logarithm of the rotation values and the standard error are shown in Table V for each fabric when tested with the blade abradant. The standard error again remains fairly constant and independent of the magnitude of the logarithmic values. The effect of any construction factor or combination of construction factors is clearly indicated.

Mathematical Expression of the Relation Between Construction Factors and Resistance to Abrasion

The important part of the present paper is concerned with the following questions: What do the results mean? What deductions, correlations, interpretations, interpolations, extrapolations, and conclusions can be drawn from these results?

By plotting log R values against nominal values of any one of the construction factors, the effect of that factor is given by the results for eight pairs of fabrics. The graphs form a family of eight essentially parallel lines; the slope of each indicates the effect of that factor. Furthermore, the displacements between these lines indicate the effects of the other construction factors. It is possible to derive analytical expressions which relate log R to the construction factors, and it is simple to combine these expressions to obtain a general equation for log R as a function of all four construction factors. The simplest equation is

$$\log R = a + bW + cF + dE + eP,$$

where W, F, E, and P are warp yarn number, filling yarn number, ends, and picks, respectively, and a, b, c, d, and e are constants.

The equation for the blade abradant is

$$\log R_1 = 1.800 - 0.090W - 0.050F + 0.012E + 0.060P.$$

The equation for the abrasive paper abradant is

$$\log R_2 = 1.740 - 0.080W - 0.030F + 0.015E + 0.020P.$$

The observed values of log R are plotted in Figure 5 against those computed from the above equations. The plotted points lie within ± 5% of a straight line drawn at equal angles, 45 degrees, to the coordinate axes, except for the fabrics referred to earlier, for which the observed values are considerably larger

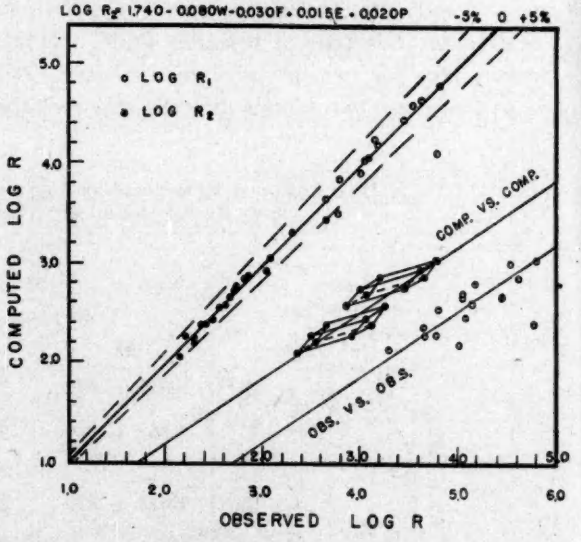

FIG. 5. *Logarithm of observed rotations of abrasion,* R, *plotted against computed values of log* R.

than the computed values. Since both equations represent the observed values very well, it seemed logical to expect that if the values computed from one equation are plotted against those computed from the other equation, the points would fall on a straight line; in other words, the fabrics would be ranked in the same order by the computed values from the two equations. As can be seen in Figure 5, the plotted points actually do not fall on the same line. In fact, they are scattered in much the same way, only very regularly, as are the observed log R values when they are plotted against each other (see Figure 5).

Each equation represents a plane—*i.e.*, noncurved, 4-dimensional solid in a 5-dimensional space. For the computed values, when plotted against each other, to lie on a straight line, the necessary and sufficient condition is that these two four-dimensional solids be parallel. In other words, the direction cosines of one equation must be proportional to those of the other equation. The adjustment of the constants in the two equations which would be required in order to accomplish this satisfactorily is somewhat risky and laborious. From the plotted values it is apparent, however, that two sets of four fabrics each depart considerably from the straight line drawn through the entire set of points. These eight fabrics can be readily identified with two construction factors—namely, warp yarn number and picks. It is therefore possible to adjust the coefficients for these two factors and the constant in one equation

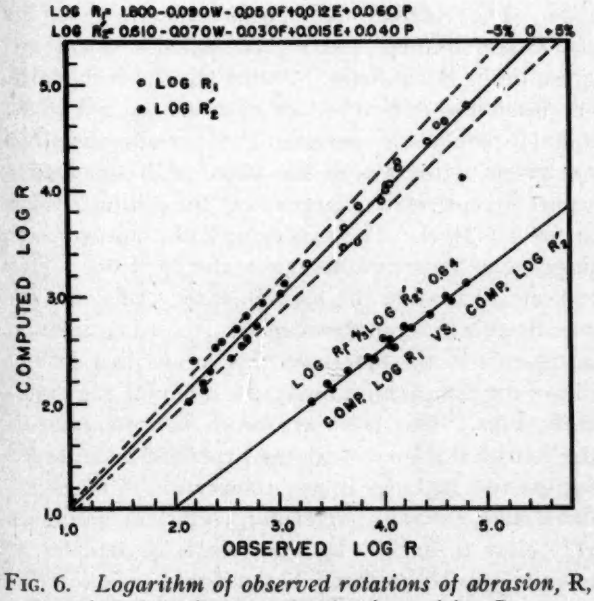

FIG. 6. *Logarithm of observed rotations of abrasion,* R, *plotted against computed values of log* R.

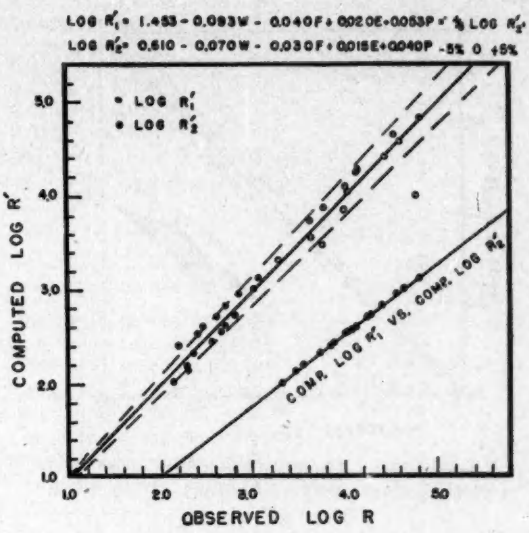

FIG. 7. *Logarithm of observed rotations of abrasion,* R, *plotted against computed values of log* R′.

so that the two groups of points will fall on the straight line drawn through the other two groups of points. The new equation is

$$\log R'_2 = 0.610 - 0.070W - 0.030F + 0.015E + 0.040P.$$

In Figure 6 are shown the plotted points corresponding to the newly computed values of log R'_2. The fit of the observed *versus* computed points is definitely poorer than before. However, the fit of the computed *versus* computed points is definitely better, and a simple equation,

$$\log R_1 = \tfrac{4}{3} \log R'_2 + 0.64,$$

can be written for the line through these points. By substituting the adjusted equation for log R'_2 in this simple equation, an adjusted equation is obtained for log R'_1—*viz.*,

$$\log R'_1 = 1.453 - 0.093W - 0.040F + 0.020E + 0.0053P.$$

The plotted points of the computed values from the two adjusted equations all fall on a straight line, as is shown in Figure 7. According to the computed values from the two adjusted equations, the sixteen fabrics are now ranked identically for each abradant. However, the fit of the computed *versus* the observed values is definitely poorer than was the case for the original equations (compare Figures 7 and 5).

It should not be inferred that the functional relationships derived above for the abrasion results of

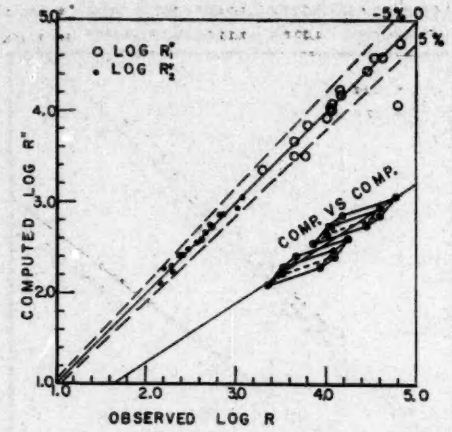

FIG. 8. *Logarithm of observed rotations of abrasion,* R, *plotted against computed values of log* R″.

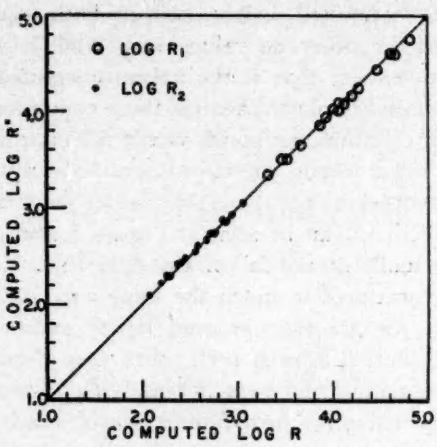

FIG. 9. *Computed log* R *plotted against computed log* R″.

the sixteen cotton fabrics are necessarily the best and only ones possible. The data can be represented equally well by the following general equation:

$$\log R = \log Ro + a \log W + b \log F + c \log E + d \log P,$$

or

$$R = W^a F^b E^c P^d \times Ro,$$

where a, b, c, d, and Ro are constants. The equation for the results obtained with the blade abradant is

$$\log R''_1 = -8.000 - 2.48 \log W - 0.86 \log F + 2.33 \log E + 6.62 \log P,$$

or

$$R''_1 = W^{-2.48} F^{-0.86} E^{2.33} P^{6.62} \times 10^{-8}.$$

The equation for the results obtained with the abrasive paper abradant is

$$\log R''_2 = -3.22 - 2.22 \log W - 0.70 \log F + 2.79 \log E + 2.16 \log P,$$

or

$$R''_2 = W^{-2.22} F^{-0.70} E^{2.79} P^{2.16} \times 6 \times 10^{-4}.$$

The observed values of log R are plotted in Figure 8 against the log R'' values computed from these new equations. All of the plotted points, except two, lie within ± 5% of a straight line drawn at equal angles, 45 degrees, to the coordinate axes, as was true in Figure 5. The computed log R''_1 values are also plotted in Figure 8 against the computed log R''_2 values, and the points are distributed as in Figure 5. The computed log R values are plotted against the computed log R'' values for both abradants in Figure 9. The points are well represented by a straight line drawn at equal angles to the coordinates, indicating that the observed data can be equally well represented by the two general empirical equations.

Effect of Rate of Abrasion on the Rank Correlation of Results

Frequently the interpretations of abrasion data are based almost entirely upon the relative rankings and rank correlation coefficients, such as the Kendall coefficient. It seemed worth-while to study the data from these viewpoints also. The results are summarized in Table VI. The various pairs of ranking which were compared are indicated in the first column. The Kendall rank coefficients are given in the second column, and the computed t values are given in the last column. At the bottom of the table are listed the critical values of t for the 5%, 2%, and 1% probability levels. The various equations are given at the top of the table. All computed t values except two are larger than the critical t value at the 1% level. The two exceptions, however, are larger than the critical t value at the 2% level. This indicates that all of the Kendall rank coefficients are significantly different from zero. According to some statements in the literature, this means that in any one of the comparisons made, the rankings are essentially alike. This is an erroneous interpretation of the statistical theory of testing hypotheses. In order for the two rankings in any comparison to be essentially alike, the rank correlation coefficient should be very close to unity. In relatively large samples, it is quite possible to obtain a significant rank correlation when the rank correlation coefficient is far below

TABLE VI. RANK CORRELATIONS

$$\text{Log } R_1 = 1.800 - 0.090W - 0.050F + 0.012E + 0.060P$$
$$\text{Log } R_2 = 1.740 - 0.080W - 0.030F + 0.015E + 0.020P$$
$$\text{Log } R_1' = 1.453 - 0.093W - 0.040F + 0.020E + 0.053P$$
$$\text{Log } R_2' = 0.610 - 0.070W - 0.030F + 0.015E + 0.040P$$
$$\text{Log } R_1'' = -8.000 - 2.48 \log W - 0.86 \log F + 2.33 \log E + 6.62 \log P$$
$$\text{Log } R_2'' = -3.22 - 2.22 \log W - 0.70 \log F + 2.79 \log E + 2.16 \log P$$

Comparisan	Kendall rank coefficient	t value	Comparison	Kendall rank coefficient	t value
Obs. R_1 *vs.* obs. R_2	0.58	2.66	Obs. log R_1 *vs.* comp. log R_1'	0.77	4.52
Obs. log R_1 *vs.* obs. log R_2	0.60	2.81	Obs. log R_2 *vs.* comp. log R_2	0.93	9.48
Comp. log R_1 *vs.* comp. log R_2	0.73	4.00	Obs. log R_2 *vs.* comp. log R_2'	0.82	5.37
Comp. log R_1 *vs.* comp. log R_2'	0.85	6.05	Comp. log R_1 *vs.* comp. log R_1''	0.93	9.48
Comp. log R_2 *vs.* comp. log R_1'	0.88	6.71	Obs. log R_1 *vs.* comp. log R_1''	0.80	5.00
Comp. log R_1 *vs.* comp. log R_1'	0.85	6.05	Comp. log R_2 *vs.* comp. log R_2''	0.93	9.48
Comp. log R_1' *vs.* comp. log R_2'	1.00	∞	Obs. log R_2 *vs.* comp. log R_2''	0.93	9.48
Obs. log R_1 *vs.* comp. log R_1	0.87	6.59	Comp. log R_1'' *vs.* comp. log R_2''	0.73	4.00

Probability level	Critical value of t
5%	2.145
2%	2.624
1%	2.977

unity—of the order of 0.4 or 0.5, for example. What the test of significance, if positive, really shows is a likelihood that the rankings are not entirely random with respect to each other—in other words, that the true correlation is not zero, or very close to zero.

In Table VII are shown the values for two of the sixteen fabrics. Fabric A is significantly better than fabric B according to tests with the blade abradant. The reverse is indicated for the abrasive paper abradant. According to the adjusted equations, these two fabrics are not different in abrasion-resistance. Although fabric B is heavier than fabric A, it is believed that fabric A is equal to, if not significantly better than, fabric B in resistance to abrasion; and it is believed further that this would be confirmed by tests in service.

TABLE VII. COMPARATIVE ABRASION-RESISTANCE OF COTTON FABRICS A AND B BY TWO TESTING PROCEDURES

Fabric	A	B	A − B
Picks per inch	55	45	10*
Ends per inch	84	84	0
Filling yarn number	8	12	−4*
Warp yarn number	16	10	6*
Observed log R_1	4.144	4.043	0.101*
Computed log R_1	4.268	4.008	0.260*
Observed log R_2	2.613	2.711	−0.098*
Computed log R_2	2.580	2.740	−0.160*

* Differences are highly significant.

A number of other similar comparisons can be made, as can be seen in Figure 10, which is an enlargement of a portion of either Figure 5 or 8. The cloth construction factors are indicated. The effect of a change in any one factor on the abrasion-resistance is clearly shown; the effect of a change in two or more factors is indicated as well. It is apparent from Figure 10 that the ranking of a number of pairs of fabrics may be reversed by the two testing procedures. These reversals arise primarily, but not necessarily, when two or more factors are varied simultaneously. The absence of perfect rank correlation between the two abradants is due mainly

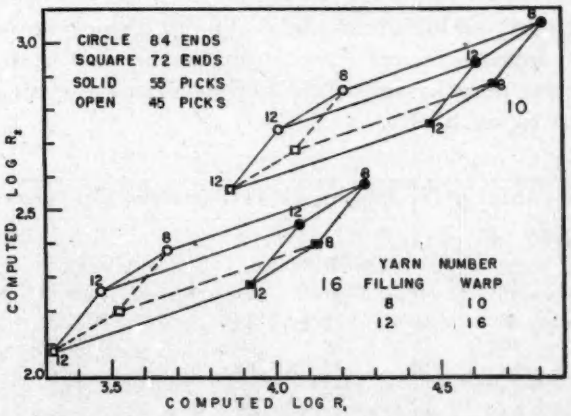

FIG. 10. *Computed log* R_1 *plotted against computed log* R_2.

to the fact that a given change in any one construction factor does not always result in quantitatively comparable changes in the resistance to abrasion by both abradants. In other words, the results obtained with one abradant may be more sensitive to such a change than those obtained with the other abradant.

The primary difference between the two abradants was in the kind of abrasion and in the rate of abrasion. The difference in the latter was more than tenfold. Such a difference, and even much greater, usually exists between service tests and laboratory wear tests. By analogy, can it therefore be concluded that similar reversals in rankings should be expected when service and laboratory abrasion test results are compared? The answer not only should be, but is, affirmative.

The results of laboratory and service wear tests on carpets [8] fully confirm this conclusion. The carpets tested differed systematically not only in construction factors but also in weave. The functional relationship for the results obtained with two different machines varied greatly with the weave. It is possible, therefore, to select for comparison many pairs of carpets for which their ranking by the two testing machines is reversed. Also, the functional relationship for the results obtained with either machine and those obtained in service tests varied greatly with the weave. Again, it is possible to select for comparison many pairs of carpets for which their ranking in the service wear test is reversed from that obtained with either machine. Even within a given weave such comparisons can be made between carpets when a construction factor, such as pitch or pile height, is varied systematically. The departure of the results for these carpets from the over-all functional relationship for a given weave is appreciable and the explanation is now clear. These remarks support those made above concerning the cotton fabrics.

Significance of Results

As in many fields of research, the most valuable information is often lost or masked by an overzealous attempt to make all points satisfy a simple functional relationship and by juggling of constants to obtain perfect rankings and rank correlations. The subject of abrasion measurements and correlations with service tests embraces many complex factors. Much work remains to be done. Abrasion tests can have great value only if they are carried out judiciously and systematically and if the results are interpreted critically.

It is also clear from Figure 10 that this graph and also the empirical equations can be useful in predicting the resistance to abrasion of fabrics belonging to this series which were not tested by interpolation and, to a limited degree, by extrapolation. These predicted values are valid for both abradants used, even though the ranking may be reversed. Eight fabrics were selected more or less at random from the remaining untested cotton fabrics of the large series. The values of log R were computed for both abradants, using the two general empirical equations. These values are given in Table VIII. Six specimens of each fabric were tested, and the average of the observed log R values was computed for each fabric and abradant. The observed values are also given in Table VIII. The observed values agree remarkably well with the predicted values.

This discussion indicates that for either abradant it is possible to find empirical equations which express the measured values of the resistance to abrasion quantitatively in terms of four fabric construction factors. Presumably, these expressions could be generalized to include other fabric and yarn construction factors. However, it is not apparent how such important factors as weave, for example, could be included since it is difficult to characterize weaves or differences in weave by numerical values. There

TABLE VIII. COMPARISON OF PREDICTED AND OBSERVED VALUES FOR LOG R FOR 8 ADDITIONAL COTTON FABRICS

Fabric construction				Blade abradant			Abrasive paper abradant		
W	F	E	P	Obs. log R_1	Comp. log R_1	Comp. log R_1''	Obs. log R_2	Comp. log R_2	Comp. log R_2''
10	10	72	55	4.65	4.56	4.51	2.81	2.82	2.80
10	8	78	50	4.48	4.44	4.40	2.93	2.87	2.88
13	10	72	55	4.36	4.30	4.22	2.53	2.58	2.54
10	12	78	50	4.14	4.24	4.25	2.74	2.75	2.75
13	10	84	45	3.86	3.84	3.80	2.53	2.56	2.55
16	8	78	50	3.77	3.90	3.89	2.38	2.39	2.42
16	12	78	50	3.67	3.70	3.74	2.23	2.27	2.30
16	10	84	45	3.55	3.57	3.58	2.31	2.32	2.35

are undoubtedly other construction factors, such as finishes and chemical treatments, kind of fiber, and so on, which fall in this same category. It appears almost hopeless, therefore, to expect to find a single laboratory evaluation procedure or method which would correctly evaluate all kinds and types of fabrics in terms of service or performance results, even if the latter could be explicitly defined and evaluated. One is tempted to ask, "Who would be so foolish as to make such an attempt?" The fact remains that there are many who do. The reason why so many attempts are made is that quite often a very good correlation is found between laboratory abrasion tests and service wear tests when only a few and similar items are involved. Fortunately, or unfortunately, it must be admitted that even such limited information is extremely valuable, and laboratory abrasion tests are certainly to be encouraged and not discouraged.

If it is assumed on the basis of the data discussed in this paper that a logarithmic function of a measured abrasion value is a reasonably close approximation for quantitatively expressing the resistance to abrasion, then it is appropriate that some consideration be given to the definition of a universal abrasion-resistance index, I, and to a unit for this index. The very general relationship

$$I = k \log_B(R/Ro)$$

for such an index has three parameters—*viz.*, k, B, and Ro—and is therefore very flexible to fit the results of almost any set of laboratory and service tests. The numerical values of k, B, and Ro would have significant and practical meanings. They can only be evaluated after adequate test results, both laboratory and service, are available for correlation purposes. In this paper, B was arbitrarily chosen as 10, but that still leaves two parameters, k and Ro, to be defined and evaluated. The value of Ro probably would be closely associated with the sensitivity of the abrasion tests, whereas the value of k would probably vary somewhat with the type and construction of the material being tested. Time and effort will give the answer.

Conclusions

An effort is made in this paper to indicate the importance of the type of abradant with respect to rate and nature of abrasion and results obtained. It is shown that the effect of four fabric construction factors can be quantitatively evaluated for two very different types of abradants. Although it was possible to show that the observed and computed rankings of the sixteen fabrics were not significantly different for the two abradants, based upon the t values computed from the Kendall rank coefficients, nevertheless it was concluded that the sixteen fabrics were not evaluated relatively the same by the two abradants. As a matter of fact, for two abradants which differ so greatly in type and rate of abrasion, it should not be expected that the relative evaluation would be the same for such a group of fabrics or that either would necessarily agree with the relative evaluation in service or performance tests. The absence of perfect rank correlation between the results obtained with two very different abradants is mainly due to the fact that a given change in any one construction factor does not always result in quantitatively comparable changes in the resistance to abrasion. In other words, the results obtained with one abradant may be more sensitive to such a change than those obtained with the other abradant. The results of systematic abrasion tests are not worthless, however, but are of great value and importance in development research, control of quality in manufacturing, and, in a limited degree, for purchase specification purposes. Eventually, enough information may become available so that intelligent estimates of service or performance values may be made.

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Cellulose Studies

Part XVI. The Reaction of Cellulose with Formaldehyde*

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Abstract

A new method for reacting cellulose and formaldehyde in the vapor phase using acid catalysts is described. Acids as weak as boric acid were effective in introducing up to 6% covalently bonded formaldehyde. The results of reaction conditions where catalyst concentration ranged from 1%–10% and reaction temperature ranged from 110°–150°C are presented.

A chemical investigation of the structure of the product of the reaction showed that formaldehyde preferentially substitutes the secondary hydroxyl groups of cellulose to yield a structure represented by the general formula R—O—CH_2—O—R′, where R and R′ indicate glucose residues in parallel chains.

Introduction

The reaction of cellulose with formaldehyde using an acid catalyst was first reported by Eschalier [4]. This study was extended by Meunier and Guyot [13] and Cross and Bevan [2]. The former authors postulated that methylene bridges, —O—CH_2—O—, were formed between two glucose residues of the cellulose during the reaction. Wood [20] disputed their conclusion and claimed that the methylene

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bridges were formed on two hydroxyl groups of the same glucose residue, or, alternatively, that hydroxymethyl groups, R—O—CH_2OH, were formed on the hydroxyl groups of the cellulose. Schenk [16] disputed Wood's proposed course of reaction and postulated that the marked change in properties observed after the interaction results from reaction at the surface of the micelles or crystallites of the cellulose fiber. According to his views, formation of cross-linkages between two different, adjacent cellulose molecular chains decreases the penetration of reacting and solubilizing solutions.

Dillenius [3] reviewed the literature and presented data showing the effect of this reaction on several properties of cellulose, such as alkali solubility, swelling in water and alkali, etc. The striking effect of the introduction of relatively small amounts of formaldehyde on these properties led him to conclude that random cross-linking by formaldehyde binds adjacent chains of cellulose molecules together into a more rigid structure which resists the penetration of reagents.

Gruntfest and Gagliardi [6] reported results showing the catalytic efficiency of acids of decreasing strength under standard reaction conditions. They soaked cellulose samples in aqueous solutions containing 1% of the acid and 20% formaldehyde; then baked the samples at 150°C for 1 hr. Measurements of the weight gain by the product after buffer washing indicated that mild acids (dissociation constant $K = 2 \times 10^{-4}$ or less) did not catalyze the reaction under these conditions.

Goldthwait [5] recently studied the reaction of cellulose with formaldehyde in two separate nonaqueous systems, glacial acetic acid and acetone, and found that a sharp drop in dye uptake of the product occurred although the formaldehyde content was quite low, 1.5% HCHO or less. He pointed out that this drop in dye uptake could not have been entirely due to substitutional blocking of hydroxyl groups of cellulose by formaldehyde because the blocking of an equal number of hydroxyl groups with acetyl groups would not produce such a marked reduction in dyeing capacity. Therefore, he suggested that this dye-resistance was due to cross-linking of different cellulose molecules and a consequent reduction in the ability of the fiber to swell in the dye solution.

Although there has been considerable study on the results of reactions of cellulose with formaldehyde under various conditions as outlined above, no conclusion as to the actual chemical structure of the product has been reached. The present paper attempts to extend the knowledge of the structure of this product. The results presented allow more accurate analysis of the course of this reaction.

Previous interpretations of the effect of the reaction on the textile properties of cellulose have, in some cases, failed to distinguish between physically adsorbed formaldehyde and chemically bonded formaldehyde. Although it cannot be denied that adsorbed formaldehyde does have some effect on the textile properties of cellulose, Dillenius [3] has shown that the major textile property changes in the cellulose molecule are due to formaldehyde chemically reacting with cellulose. Consequently, all formaldehyde-treated samples discussed herein were washed with hot water to remove adsorbed formaldehyde before further investigation.

The formaldehyde remaining in the methylene cellulose after hot-water washing is designated as "fixed formaldehyde."

Preparation of Methylenated Cellulose

In preliminary experiments, methods for introduction of formaldehyde into cellulose with a minimum degradation of fiber properties were investigated. Samples of cotton warp yarn (75% $1\frac{1}{16}$-in. Strict Low Middling and 25% $1\frac{1}{16}$-in. Middling blend) with nominal tensile strength of 500 g. were prewashed with soap and water, and then washed free of soap with distilled water. This washed yarn was used as the starting material for all experiments discussed in this paper.

The first set of experiments was designed to test the efficiency of various acids in aqueous solution as catalysts for the reaction. Samples of the washed yarn were soaked in aqueous solutions containing 20% formaldehyde by weight plus varying amounts of acid catalyst, and then wrung out to 100% weight gain (wet) based on the sample weight. The treated samples were then baked in an oven at 150°C for 3 hrs. The products were washed free of adsorbed formaldehyde with hot distilled water. Formaldehyde content of the products was measured by the colorimetric method of Hoffpauir, Buckaloo, and Guthrie [10].

The results of the first set of experiments are presented in Table I, which shows the comparative effectiveness of boric acid, acetic acid, and sulfuric acid as catalysts for the reaction between cellulose and

TABLE I. EFFICIENCY OF ACIDS IN CATALYZING THE REACTION BETWEEN CELLULOSE AND FORMALDEHYDE *

Acid	% Acid on dry sample	% Formaldehyde fixed
Boric acid	0.12	0.04
	3.2	0.10
	4.8	0.17
	5.7	0.12
Acetic acid	1.9	0.08
	3.9	0.09
Sulfuric acid	0.006	0.09
	0.012	0.12
	0.035	0.18
	0.075	0.38
	0.130	0.59
	0.294	Product charred

* Reaction conditions: baking temperature, 150°C; baking time, 3 hrs.

formaldehyde. These results clearly indicate that sulfuric acid was the most effective catalyst, but qualitative examination of the product (discoloration and residual yarn strength) revealed that considerable fiber degradation had occurred with this acid.

Since samples of considerably higher "fixed" formaldehyde content were required for structural study, a new method was developed for carrying out the reaction.

Washed yarn samples were soaked in an aqueous solution of the acid catalyst, then wrung out to 100% weight gain (wet) of catalyst solution, and dried in an oven at 55°C. This acid-treated sample was sealed into a glass tube with solid paraformaldehyde (10% of the weight of the sample). The glass tube was placed inside a metal shielding tube, and the sample baked in an oven at temperatures of 110° to 150°C. After baking for 1 to 24 hrs., the tube was cooled and opened, and the sample was removed and washed with hot distilled water until no trace of formaldehyde was found in the washings. Formaldehyde contents were then estimated on the washed products by the colorimetric method of Hoffpauir, Buckaloo, and Guthrie [10].

Table II, which shows the effects of catalyst concentration, baking time, and baking temperature on "fixed" formaldehyde content, indicates the effectiveness of this method for introducing "fixed" formaldehyde up to 5% by weight.

The sealed-tube method was used in the preparation of samples for studies on the structure of methylene cellulose. In some cases, samples from an initial treatment were re-treated to bring "fixed" formaldehyde content to 5% or more.

Determination of the Structure of Methylene Cellulose

Previous investigations of the reaction of formaldehyde with cellulose in the presence of acidic catalysts were concerned primarily with the effect of the reaction on the textile properties of cellulose. There has been some speculation on the nature and location of the formaldehyde introduced into the cellulose molecule, but these speculations have not been sup-

TABLE II. BORIC ACID-CATALYZED REACTION BETWEEN CELLULOSE AND FORMALDEHYDE IN A SEALED TUBE

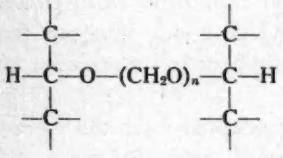
Baking temperature, 110°C			Baking temperature, 125°C			Baking temperature, 150°C		
% Acid on dry sample	Baking time (hrs.)	% Formaldehyde fixed	% Acid on dry sample	Baking time (hrs.)	% Formaldehyde fixed	% Acid on dry sample	Baking time (hrs.)	% Formaldehyde fixed
3.5	2	0.08	3.5	1	0.05	1.1	1.0	0.07
7.1	2	0.18	10.4	1	0.08	5.0	1.0	0.43
9.7	2	0.15				7.6	1.0	0.37
1.6	4	0.07	2.8	1.5	0.06			
3.5	4	0.31	4.3	1.5	0.28			
5.6	4	0.50	4.8	1.5	0.26	1.8	1.5	0.34
6.3	4	0.57	6.5	1.5	0.18	3.9	1.5	0.64
7.1	4	0.56	8.3	1.5	0.22	7.6	1.5	1.23
9.3	4	0.83	9.9	1.5	0.21			
0.9	24	0.30	3.7	24	4.63			
2.7	24	1.68	5.2	24	4.65			
4.3	24	2.32	6.1	24	4.26			
5.2	24	3.62	8.8	24	3.93			
8.1	24	3.46	9.0	24	4.41			
			10.6	24	5.02			

ported by chemical investigation of the reaction product.

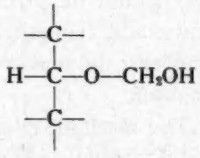
The method selected for determination of structure of methylene cellulose follows a procedure often used for identification of polysaccharides and substituted polysaccharides. It is based on methylation of the polysaccharide, methanolysis of the methylated polysaccharide to yield a mixture of methylated monosaccharide glycosides, separation and identification of these glycosides by physical or chemical methods, and reconstruction of the polysaccharide structure.

Methylation of Formaldehyde-Treated Cellulose

As a first step in the elucidation of the structure of formaldehyde-treated cellulose, it was necessary to demonstrate that during the treatment actual chemical reaction between cellulose and formaldehyde occurred. Two general formulas (1) and (2) have been proposed as representing the product of this reaction:



(1)



(2)

In formula (1), the terminal carbon atoms of the methylene bridge may be in the same or different glucose residues of the same or different cellulose chain molecules and n may be equal to one or more. This formula represents the product from the reaction of formaldehyde or formaldehyde polymers with two cellulosic hydroxyl groups. Reaction along the lines postulated by this general formula reduces the number of free hydroxyl groups in a given number of glucose residues. On the other hand, if the reaction product is best represented by formula (2), no reduction in the number of free hydroxyl groups should occur.

The usual method for determination of residual free hydroxyl groups in substituted cellulose samples is methylation and subsequent estimation of the methoxyl content of the product. The complete methylation of the hydroxyl groups of native cellulose should yield a product containing 45.5% by weight of methoxyl. Actually, only about 43% methoxyl content is attainable. This difference between theoretical and obtainable methoxyl content has not been satisfactorily explained.

Samples of formaldehyde-treated cellulose, containing approximately 5% bound formaldehyde, were methylated, using the method of Haworth [7] as modified by Steele and Pacsu [17]. The methylation procedure was repeated until no further increase in methoxyl content of the product was observed.

Results of methylations on two samples of formaldehyde-treated cotton yarn are presented in Table III. Methoxyl contents were estimated by the method of Vieböck and Schwappach [19], as modified by Clark [1]. Theoretical methoxyl contents were obtained from the calculated number of free hydroxyl groups remaining after methylenation. The calculations of free hydroxyl content were based on the assumption that each methylene bridge blocks two, and only two, hydroxyl groups per molecule of formaldehyde.

TABLE III. THE METHYLATION OF METHYLENE CELLULOSE

No. of methylations	% HCHO (Experimental analysis)	% —OCH_3 (Experimental analysis)	Calc. % HCHO* (—OCH_3 free)	Calc. % —OCH_3 (Theoretically obtainable)
		Methylation experiment No. 1		
0	5.50	—	5.50	37.1
1	4.96	25.22	5.60	36.9
2	4.78	27.10	5.45	37.2
3	4.52	31.84	5.28	37.5
4	4.64	32.28	5.43	37.2
		Methylation experiment No. 2		
0	5.46	—	5.46	37.2
1	5.24	26.91	5.90	36.5
2	4.86	31.21	5.66	36.9
3	4.81	32.44	5.64	36.9
4	4.90	32.08	5.73	36.7

* Calculated from analyzed formaldehyde content of the methylated methylene cellulose by converting to a methoxyl-free basis.

Results of an independent experiment indicated that maximum methoxyl content was obtained on methylene cellulose after four methylations, so methylations were not continued beyond the fourth treatment.

The methylation of methylene cellulose containing 5.5% "fixed" formaldehyde yields a maximum methoxyl content of 32.28%. Calculation of theoretical methoxyl content attainable upon methylation of this material indicates that 37.2% methoxyl content should have been present if complete methylation of all residual free hydroxyl groups had been attained.

If reaction occurred between polymeric formaldehyde and two free hydroxyl groups, a lesser number of hydroxyl groups per molecule of formaldehyde would be blocked and the difference between the theoretical and observed methoxyl contents would be greater than the difference obtained. Therefore, it was concluded that the reaction involves reaction of monomeric formaldehyde with two cellulosic hydroxyl groups, yielding a product represented by the structure Cell.—O—CH_2—O—Cell.

The difference obtained between theoretical and actual methoxyl contents of methylated methylene cellulose was probably due to steric hindrance of hydroxyl groups adjacent to the methylene bridges.

The striking difference in methoxyl content between methylated native cellulose (43%—OCH_3) and our methylated methylene cellulose (32%—OCH_3) was the first concrete piece of evidence that "fixed" formaldehyde in methylene cellulose is *covalently bonded* to the cellulose molecule. This bonded formaldehyde, rather than formaldehyde adsorbed on the surface of the fibers which can be removed with hot water, is responsible for the striking changes in the textile properties of cellulose after formaldehyde treatment.

The Methanolysis of Methylated, Formaldehyde-Treated Cellulose

The next step in the determination of formaldehyde-treated cellulose structure was methanolysis of the methylated sample to a mixture of methylated methyl glucosides. Separation and identification of the resulting methylated methyl glucosides would permit reconstruction of the structure of the original methylene cellulose, since the positions of the nonmethylated hydroxyl groups of the methylated methyl glucosides, other than that in the number 4 position, constitute the bonding positions of the methylene bridges.

Methanolysis was carried out according to the method of Meyer and Gürtler [14] using 1% dry hydrogen chloride in methanol as the reagent. A sample of dried, methylated methylene cellulose was sealed into a glass tube with an excess of 1% hydrogen chloride in methanol, and was heated for 60–70 hrs. at 130°C. After cooling and opening the tube, the resulting solution was filtered and neutralized with excess silver carbonate. The resulting silver chloride precipitate was filtered off, and the filtrate was evaporated under reduced pressure to yield a sirupy mixture of methylated methyl glucosides. Recovery was 91% from the methanolysis of the product (methylation experiment number 1) (see Table III).

Separation of the Methylated Methyl Glucosides

Attempted separation of the mixture of methylated methyl glucosides by molecular distillation or chromatography of the azoyl esters of these glucosides was unsuccessful. However, a method of selective solvent extraction of the mixture was developed, and was found to effect partial resolution, with concentration of trimethyl methyl glucoside into one fraction and di- and monomethyl methyl glucosides into another.

The method, which was adapted from the work of MacDonald [12], was carried out as follows:

A 6.0-g. sample of the mixed methyl glucosides obtained from the methanolysis of the product from methylation in experiment number 1 (see Table III) was dissolved in distilled water. This aqueous solution was then extracted with five portions of chloroform, and the chloroform extracts were united. The combined chloroform extracts (designated as "fraction *I*") were then extracted with water to remove entrained mono- and dimethyl methyl glucosides. This water extract was labelled "fraction *II*." The aqueous solution left after the chloroform extraction was labelled "fraction *III*."

Yields and methoxyl contents of the respective fractions are presented in Table IV. Sections *B* and *C* of Table IV show the composition of the fractions calculated from their methoxyl contents and the percent weight recovery of each of the three fractions. The trimethyl methyl glucoside was extracted from the aqueous solution by chloroform, while monomethyl methyl glucoside remained in the aqueous solution. Dimethyl methyl glucoside was only partially extracted by chloroform and conse-

TABLE IV. RESULTS OF THE CHLOROFORM EXTRACTION OF THE MIXED METHYL GLUCOSIDES FROM METHYLATED METHYLENE CELLULOSE

A—Methoxyl content of the fractions

Chloroform extracts (*I*)	50.1% —OCH_3
Water washings (*II*)	43.6% —OCH_3
Extracted aqueous solution (*III*)	34.3% —OCH_3

B—Calculated yields

	Yield of methylated methyl glucosides from methoxyl contents of the fractions			
	Trimethyl (g.)	Dimethyl (g.)	Monomethyl (g.)	
Combined chloroform extracts (*I*)	2.21	0.64	—	
Water washings of the chloroform extracts (*II*)	0.04	0.20	—	
Extracted aqueous solution (*III*)	—	1.00	1.67	
Totals	2.25	1.84	1.67	5.76
Recovery (% wt.)				96.0

C—Yields in percent of recovery

	Trimethyl (%)	Dimethyl (%)	Monomethyl (%)	Total (%)
Chloroform extracts (*I*)	38.4	11.1	—	49.5
Water washings (*II*)	0.7	3.4	—	4.1
Extracted aqueous solution (*III*)	—	17.4	29.0	46.4
	39.1	31.9	29.0	100.0

quently was found in all three fractions. The summation in section *C* shows the composition of the mixture of methylated methyl glucosides.

The trimethyl methyl glucoside yield represents the unmethylenated glucose residues in the original formaldehyde-treated cellulose. The dimethyl methyl percentage represents the fraction of glucose residues where one hydroxyl group is involved in a methylene bridge. Monomethyl methyl glucoside represents glucose residues where one hydroxyl group was involved in methylene bridge and the presence of the bridge inhibited methylation of an adjacent hydroxyl group. Thus, 60.9% of the glucose residues were involved in methylene bridges; 39.1% were not methylenated.

The theoretical yield of trimethyl methyl glucoside calculated from the formaldehyde content of the original methylene cellulose, using the assumption that each molecule of formaldehyde substitutes two, and only two, hydroxyl groups, is 39.2% if no glucose residue is involved in more than one methylene bridge. The close correspondence between the observed yield of trimethyl methyl glucoside (39.1%) and the calculated yield (39.2%) gives strong indication that the assumptions used in the calculations are correct.

Qualitative Identification of the Mono- and Dimethyl Methyl Glucoside Isomers

The known structure of cellulose and previous studies on hydrolyzed trimethyl cellulose have shown that the trimethyl methyl glucoside fraction should be composed of 2,3,6-trimethyl methyl glucoside only. On the other hand, there are three isomers possible for both dimethyl and monomethyl methyl glucoside if random distribution of the methylene bridges between the number 2, 3, and 6 hydroxyls occurs during the formaldehyde treatment.

However, if physical structure and interatomic distances of certain pairs of hydroxyl groups favor methylenation of specific pairs of hydroxyl groups of the glucose residues of cellulose, the number of isomers present in the mixture of dimethyl and monomethyl methyl glucosides should be reduced. Identification of these dimethyl and monomethyl methyl glucoside isomers would allow reconstruction of the structure of methylene cellulose.

Hirst, Hough, and Jones [8] characterized the migration of several mono- and dimethyl glucose isomers using the paper-partition chromatography method described by Partridge [15]. This method has been used to separate and identify the components of unknown mixtures of methyl glucoses by the ratio R_G, which is the distance a given methyl sugar chromatographically migrates divided by the distance a sample of 2,3,4,6-tetramethyl glucose migrates.

A sample of the mixture of mono- and dimethyl methyl glucosides (fraction *III* from the extraction) was hydrolyzed to free methyl glucose isomers by refluxing with aqueous acid solutions. The methyl glucoses were recovered after removal of the acid, and were partially dried. A drop of this mixture of mono- and dimethyl glucose isomers was placed on a piece of Whatman No. 1 filter paper which was hung vertically from a trough containing the organic layer from a mixture of 40% butanol, 10% ethanol, and 50% distilled water. Capillary action between this developer and the filter paper carried the methyl glucoses down the paper. When development was complete, the paper was removed, dried, and then sprayed with an ammoniacal silver nitrate solution

in water. Redrying of the paper produced dark reduced-silver spots at the location of the methyl glucose isomers.

The mixture of methyl glucoses from fraction-*III* glucosides produced three spots having average R_G values of 0.126, 0.332, and 0.582, which were preliminarily identified as glucose, monomethyl glucose, and dimethyl glucose, respectively. An authentic sample of glucose yielded an average R_G value of 0.118, and an authentic sample of 2,3-dimethyl glucose yielded an average R_G value of 0.673. Glucose was obviously present in fraction *III* of the methyl glucosides, but only in trace amounts, since the spot size and color density were quite low.

The attempt to identify the dimethyl glucose spot ($R_G = 0.582$) by comparison with the migration of authentic 2,3-dimethyl glucose ($R_G = 0.673$) was unsuccessful, but the result demonstrated that no 2,3-dimethyl glucose was present in the mixture. Hirst [8] reported a lower R_G value for 3,6-dimethyl glucose, but did not report a value for 2,6-dimethyl glucose. Since samples of these latter isomers were not available to us, it was not possible to choose between these remaining alternatives.

However, the absence of 2,3-dimethyl glucose shows that ***no methylene bridges were formed on the primary hydroxyl groups*** of the original glucose residues of the cellulose sample. Further evidence of the selectivity of the reaction toward secondary hydroxyl groups is presented below.

Periodic Acid Oxidation of Methylene Cellulose

Heterogeneous periodic acid oxidations measuring the consumption of buffered aqueous periodic acid have been used in the estimation of adjacent secondary hydroxyl group content of sugars and sugar polymers such as cellulose. Jackson and Hudson [11] observed the theoretical periodic acid consumptions of 1.0 mole per mole on cellulose and starch. To check their methods, a sample of the washed cotton yarn used for formaldehyde-treating studies was therefore oxidized with the periodic acid reagent at room temperature. The theoretical periodic acid consumption of 1.0 mole per mole of sample was reached after 325 hrs.

Similar periodic acid oxidation of a formaldehyde-treated cotton yarn sample containing 6.5% formaldehyde showed a maximum periodic acid consumption of only 0.1 mole per mole of sample. The methylene bridges of this sample can eliminate only 0.7 of the glycollic groupings by substitution if all reaction occurs on secondary hydroxyl groups. The observed periodic acid consumption of 0.1 mole per mole is less than the theoretical minimum periodic acid consumption of 0.3 mole per mole, so it appears that the presence of methylene bridges partially inhibits penetration of the periodic acid reagent. However, this result supports the results of paper-partition chromatography, which indicated that methylene bridges are linked through secondary hydroxyls, since methylene bridges on primary hydroxyl groups would not decrease the number of glycollic hydroxyl groups in the sample and higher periodic acid consumption would have been observed.

Periodic Acid Oxidation of the Mixture of Mono- and Dimethyl Methyl Glucoside in Fraction III

The results of paper-partition chromatography and the periodic acid oxidation of methylene cellulose showed that the dimethyl methyl glucoside in fraction *III* was not 2,3-dimethyl methyl glucoside. However, this information does not permit a choice between the other isomers which could occur. The following methyl glucoside isomers remain as possible components of fraction *III* containing mono- and dimethyl methyl glucosides: 2,6-dimethyl methyl glucoside; 3,6-dimethyl methyl glucoside; 2-monomethyl methyl glucoside; 3-monomethyl methyl glucoside; 6-monomethyl methyl glucoside.

Periodic acid oxidation of the mixture of methyl glucosides in fraction *III* was selected as a method for obtaining further information on the isomeric composition of the mixture of mono- and dimethyl methyl glucosides. 3,6-Dimethyl methyl glucoside and 3-monomethyl methyl glucoside are not oxidizable by periodic acid because they contain no adjacent hydroxyl groups. 2,6-Dimethyl methyl glucoside and 2-monomethyl methyl glucoside consume 1 mole of periodic acid per mole of glycoside, while 6-monomethyl methyl glucoside, with three hydroxyl groups on adjacent carbon atoms, consumes 2 moles of periodic acid per mole. Furthermore, 6-monomethyl methyl glucoside, and only this glucoside isomer of those listed, should yield 1 mole of formic acid during periodic acid oxidation. Therefore, periodic acid oxidation of fraction-*III* glucosides and subsequent estimation of formic acid content of the oxidized product should yield further quantitative information on this mixture.

Periodic acid oxidation of the mixture of methyl glucosides in fraction *III* and estimation of formic acid production were therefore carried out according

to the method of Hirst, Plant, and Wilkinson [9], as modified by Van Fossen [18]. A standard solution of periodic acid which had been neutralized to pH 4.2 was used as the oxidizing reagent. Formic acid produced by the oxidation was determined by titration with 0.008*N* barium hydroxide solution with the aid of a pH meter to measure the end-point.

The periodic acid oxidation of the mono- and dimethyl methyl glucosides in fraction *III* consumed 1.05 moles of periodic acid per mole of sample and produced 0.35 mole of formic acid per mole of sample.

Since all formic acid production can be attributed only to 6-monomethyl methyl glucoside, the mixture of mono- and dimethyl methyl glucosides in fraction *III* contained 0.35 mole of 6-monomethyl methyl glucoside per mole. Aqueous fraction *III* containing mono- and dimethyl methyl glucosides represented 46.4% of the total glucosides from the methylated methylene cellulose: therefore, $0.35 \times 46.4 = 16.2\%$ of the total glucosides is 6-monomethyl methyl glucoside. As shown previously, 39.1% of the total glucosides was 2,3,6-trimethyl methyl glucoside, so that a total of 55.3% (16.2% + 39.1%) of the glucosides have been quantitatively accounted for and identified.

The 0.35 mole of 6-monomethyl methyl glucoside consumed two moles of periodic acid per mole. Therefore, 0.70 mole of the 1.05 moles periodic acid consumption by the mono- and dimethyl glucoside mixture (fraction *III*) has been explained. The remaining 0.65 mole of mono- and dimethyl methyl glucoside isomers per mole of fraction *III* must account for the remaining 0.35 mole of periodic acid consumption per mole. Since the percentage of monomethyl methyl glucosides in fraction *III* consisting of 29.0% of monomethyl and 17.4% of dimethyl methyl glucosides is 62.5% (*cf.* Table IV), the percentage of unidentified monomethyl methyl glucoside in the mono- and dimethyl methyl glucosides of fraction *III* is $62.5 - 35.0 = 27.5\%$, or 12.8% of the total (46.4%) fraction *III*. This must have been either 2-monomethyl methyl glucoside or 3-monomethyl methyl glucoside.

As shown previously, the dimethyl methyl glucoside must be either 2,6- or 3,6-dimethyl methyl glucoside or both. The composition of the original glucoside mixture from methanolysis of methylated methylene cellulose therefore may be summarized as follows:

2,3,6-trimethyl methyl glucoside	39.1%
6-monomethyl methyl glucoside	16.2%
unknown dimethyl methyl glucoside	31.9%
unknown monomethyl methyl glucoside	12.8%
2,3-dimethyl methyl glucoside	0.0%

Trial-and-error calculations using the known periodic acid consumptions of 2- and 3-monomethyl methyl glucosides together with those of 2,6- and 3,6-dimethyl methyl glucoside indicated that all of these isomers must have been present to account for the observed periodic acid consumption. The methylene bridges must therefore have been 2–3 or both 2–2 and 3–3. (2–2 indicates bridging from the number 2 carbon atom of one glucose residue to the number 2 carbon atom of another glucose residue.) Pure 2–2 or 3–3 bridging by the methylene groups would not explain the observed periodic acid consumption by the mono- and dimethyl methyl glucoside mixture in fraction *III*.

Conclusions

(1) A new method for reacting cellulose with formaldehyde in the presence of acid catalysts as mild as boric acid produced methylene cellulose containing up to 6.5% covalently linked formaldehyde.

(2) Methylation of methylene cellulose showed that one molecule of formaldehyde condensed with two hydroxyl groups of the glucose residues of cellulose to form the methylene bridge. None of the bridges was formed from polymers of formaldehyde.

(3) Formaldehyde reacts selectively with the secondary hydroxyl groups of cellulose in the formation of methylene cellulose.

(4) All methylene bridges were formed between hydroxyl groups of different glucose residues of the cellulose; the radical change in textile and physical properties observed after formaldehyde treatment of cellulose indicated that these glucose residues must usually have been on different cellulose molecules, but no direct proof of this postulate has been obtained.

(5) The methylene bridges were either all 2–3 linkages or a mixture of 2–2 and 3–3 linkages. The results did not allow a definite choice between these two possibilities.

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Effects of Tension on the Swelling of Cotton Fibers

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Abstract

Changes in the cross-sectional area and circularity of cotton fibers tensioned in water and other media have been measured microscopically. It was found that the area increased significantly over that brought about by water-swelling alone. Fibers tensioned in bundle form at 0.45 g./grex for 1 hr. in water showed an average increase of 98% in area compared to dry untensioned fibers, and an increase in circularity (axis ratio) of 57%. These increases were not retained on drying, even when tension on the fibers was maintained.

Immersion without tension in urea solution, ethylamine, or sodium hydroxide of mercerizing strength, followed by removal of the reagent and drying, in each case produced increases in area and circularity over those of the untreated fibers. Tensioning at 0.45 g./grex during immersion in these reagents increased the circularity, but decreased the area with respect to the untensioned fibers.

The elongation of fiber bundles tensioned in the various media was measured. The sodium hydroxide solution produced the greatest elongation.

THE NORMAL SWELLING of the cotton fiber in water has been shown to be about 25%–30% [3], but little information exists as to whether this swelling is increased or decreased when the fibers are in tension. Specific information on this point is desirable, since yarns and fabrics during their construction, processing, or use are subjected to varying degrees of longtudinal stress in both the wet and dry conditions. Lyons [2] has shown that the application of tension close to the breaking point of bundles of wet cotton fibers produces an increase in total cross-sectional area, lumen area, and, in some cases, cell-wall area. In that work it was pointed out that stretching of a collapsed tube containing convolutions would cause the cross section of the tube to open and assume a circular form. It is known that the cross-sectional size and shape of fibers are related to a number of other fiber characteristics, including tensile properties, resilience, and behavior during dyeing or mercerizing processes. It was considered of interest to determine the changes in these aspects of fiber geometry during and after tensioning in the wet state. In the investigations described here fiber bundles were stretched in water and other media and were compared with untensioned dry fibers. Elongation of the fiber bundles during tension was also measured.

Microscopical measurements of the cross-sectional area of the fibers showed that after swelling in water, without tension, the cross-sectional area increased 27% over that of the dry fibers. Under tension, the increase in area was as great as 98%; circularity of the fiber sections also increased. These effects were not permanent, however, for when the fibers were dried they returned toward their original size and shape, even when dried under load. The utility of the phenomena observed apparently is significant only in those uses of cotton where the wet fiber is under longitudinal stress, as in fire hose or similarly used water-resistant fabrics. The effect of mercerization, as is well known, is to make cotton fibers more cylindrical; this effect can be increased by tensioning during the process.

The observed increase in the circularity of the wet-tensioned fibers bears out the mechanism of stress relief in stretching of a collapsed tube proposed by Lyons [2]. While the thickness of the cell wall tends to be drawn down as its length increases, opening of the partially collapsed tube to become more circular increases the cross-sectional area and the total volume of the fiber.

Experimental

Materials

All experiments were conducted on samples from the same lot of Wilds 13 cotton, which had the following fiber properties: average staple length (Fibrograph), 1 in.; maturity count, 84%; Micronaire

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linear scale fineness, 3.9μg./in.; Pressley strength, 8.1 lbs./mg. Media other than water in which the fibers were tensioned were: 50% urea solution, ethylamine, 18% sodium hydroxide. The water used contained a small amount of wetting agent.

Preparation of Fiber Bundles and Tensioning

Bundles of fibers to be tensioned were prepared by hand-combing a tuft until the fibers were parallel and then cutting to a length of 2 cm. Bundles weighing 2 to 3 mg. were fastened at each end to cords by means of resorcinol-formaldehyde resin. The number of fibers per milligram weight of cotton in the bundles was found to be relatively constant, the average of seven bundles being 277 fibers/mg., with a standard deviation of 3.8. The ratio of thick- to thin-walled fibers was found to not change significantly from bundle to bundle.

The bundles, with cords attached, were placed in glass tubes, each of which was stoppered at the lower end with a rubber stopper having a small screw eye to which one of the cords was tied. The cord at the upper end of the bundle was run over pulleys, and weights were added to apply tension. Efforts were made to minimize twisting by adjustment of the cord. A small amount of tension was placed on the bundle to stabilize it while water or other liquid was poured in the tube; the full tension of the experiment was applied immediately after addition of the liquid.

Tensions were applied for periods of 1 hr., and in one experiment for a period of 75 hrs. Loads of approximately 0.11, 0.22, and 0.45 g./grex (equivalent to 0.12, 0.25, and 0.5 lb./mg., respectively) were applied. Loads greater than 0.45 g./grex usually ruptured many fibers in the bundle and therefore were not used.

Fiber bundles tensioned in urea solution were rinsed in warm water to remove the urea. Ethylamine was removed with hot chloroform. Sodium hydroxide was removed by washing with water until the rinsings were neutral to litmus. In experiments with these liquids, the bundles were kept under tension until dry.

Cross-Sectioning

To obtain cross sections of the bundles for measurements in the wet state, Epon resin * was used as the embedding medium. After tensioning in water, the bundle was removed from the glass tube, without removing the water adhering, and was placed in a gelatin capsule from which the ends had been cut. The cord was passed through a cork stopper closing the lower end of the capsule. Unpolymerized resin was poured into the capsule to cover the bundle, and the sample was placed under vacuum for 15 min. The encapsulated bundle was then attached to the ceiling of an oven by its upper cord, and the same tensioning weights were hung from the lower cord. The Epon resin was polymerized at 45°C overnight.

The composition of the resin used was essentially that recommended by the manufacturer for general use. There is apparently no chemical combination between the cellulose of the cotton fiber and the Epon resin, for the embedded fibers were readily dissolved by dilute cuprammonium hydroxide. The embedded specimens were sectioned on a rotary microtome. The polymerized Epon was not removed from the sections. Styrene was found to be a satisfactory mountant for examination of the sections under the microscope. Excellent adhesion of the fiber surface to the Epon resin was apparent in all of the specimens observed. Hence, it is very probable that the mechanical state of the fiber embedded under tension is maintained in the cross sections cut from the embedded sample.

The use of methyl methacrylate for embedding fiber bundles in tension was found to produce abnormal distension and ballooning of the fibers. The apparent cause of this phenomenon is the swelling of the methacrylate, which polymerizes more rapidly in the lumen of the fiber.

Fiber bundles in the dry state were sectioned by means of the modified Hardy technique [1], except for those bundles dried after stretching in water.

Measurements

Photomicrographs of the fiber cross sections were made at 500 × actual size, and subsequently were enlarged to 1,000 ×. Areas of individual fibers were measured with a polar planimeter. Circularity was determined as the ratio of the minor to the major diameter of the fiber (unity for a true circle). Two-hundred fibers were measured in each experiment, except where noted.

A measuring microscope was used to observe the elongation accompanying the tensioning of the fiber

* Adhesive produced by the Shell Chemical Company [4]. The mention of trade products does not imply that they are endorsed by the Department of Agriculture over similar products not mentioned.

TABLE I. CROSS-SECTIONAL CHANGES OF WET COTTON FIBERS UNDER TENSION

Treatment	Area		Circularity		Increase over control	
	Mean (μ^2)	Standard error (μ^2)	Mean	Standard error	Area (%)	Circularity (%)
Control, soaked in water 1 hr., dried	117	1.7	0.343	0.009	—	—
No tension, embedded wet*	148	2.0	0.375	0.011	27	9
0.11 g./grex; wet-stretched 1 hr.; embedded wet	179	3.2	0.413	0.012	53	21
0.22 g./grex; wet-stretched 1 hr.; embedded wet	209	3.4	0.488	0.011	78	42
0.45 g./grex; wet-stretched 1 hr.; embedded wet	232	4.2	0.538	0.014	98	57
0.45 g./grex; wet-stretched 75 hrs.; embedded wet	226	3.6	0.566	0.013	93	65
0.45 g./grex; wet-stretched 1 hr.; dried with load	145	2.4	0.424	0.011	24	24
0.45 g./grex; wet-stretched 1 hr.; dried without load	133	2.0	0.398	0.011	14	16

* Data from 400 fiber measurements.

bundles. Pieces of 30-mil wire were tied tightly around the bundle at each end to serve as reference points. In order to prevent any twisting of the bundle in these observations, wires were used in place of cords, and these were attached to the bundle by means of battery clips. The load applied in the elongation experiments was 0.45 g./grex. Observations were made when the distance between reference points remained constant for 10 min. Elongation was calculated as the percentage increase in distance between the reference points of the bundle, based on the length observed in the dry unloaded bundle. Groups of 3 to 6 bundles were measured in each liquid, and the data reported are the means of the observations on each group.

Results

Swelling in Water

The results of experiments on fibers tensioned in water are listed in Table I. Water-swelling without tension produced an increase in cross-sectional area and a small increase in circularity. With tension, these changes were increased further. It is seen from Table I that the amount of the increase in cross-sectional area of the loaded fibers is related to the size of the load placed upon them. Likewise, there is a positive correlation between the increases in area and in circularity of the fibers.

In Figure 1 are shown the cross-sectional appearances of the wet-untensioned fibers and those tensioned for 1 hr. under a load of 0.45 g./grex. The

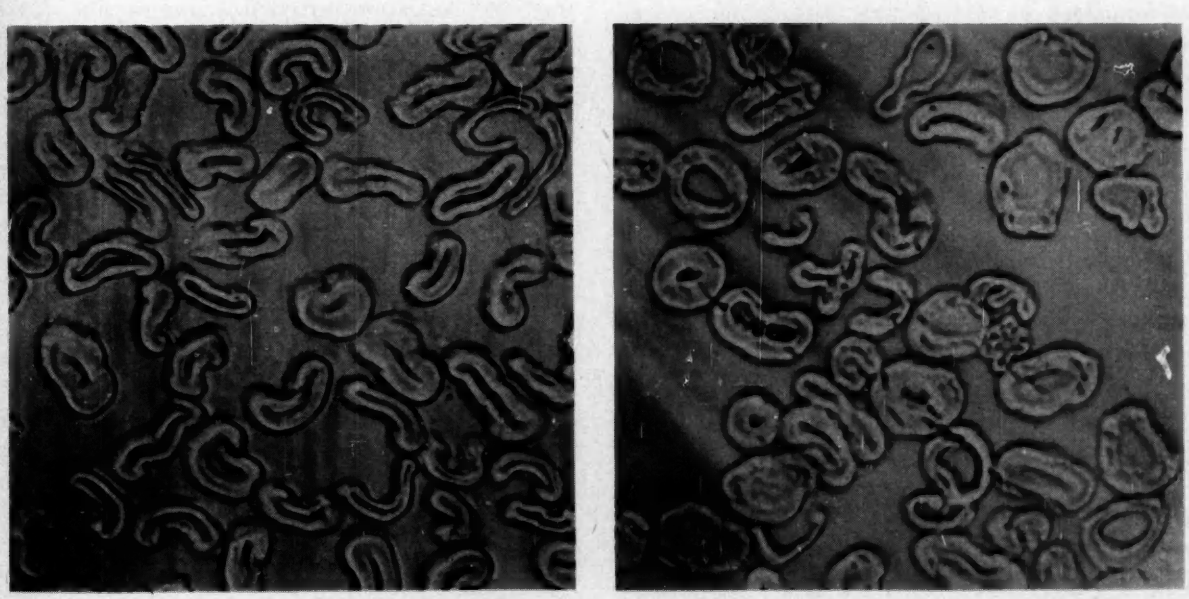

FIG. 1. *Cross sections of wet-untensioned (left) and wet-tensioned (right) (0.45 g./grex) cotton fibers embedded in Epon resin. Magnification, 750 ×.*

TABLE II. CROSS-SECTIONAL CHANGES OF COTTON FIBERS TENSIONED IN VARIOUS REAGENTS *

Treatment	Area		Circularity		Increase over control	
	Mean (μ^2)	Standard error (μ^2)	Mean	Standard error	Area (%)	Circularity (%)
Control, soaked in water 1 hr., dried	117	1.7	0.343	0.009	—	—
50% urea, no tension	138	2.2	0.393	0.009	18	15
50% urea, tensioned	133	1.9	0.479	0.011	14	40
Ethylamine, no tension	140	2.5	0.434	0.010	20	27
Ethylamine, tensioned	113	2.3	0.522	0.013	−4	52
18% sodium hydroxide, no tension	170	2.2	0.746	0.005	45	118
18% sodium hydroxide, tensioned	145	1.8	0.807	0.007	24	134

* Tensioned bundles were held under 0.45 g./grex load for 1 hr. in reagent, the reagent was removed, and the bundle allowed to dry under tension.

average difference in area of the fibers pictured is 57%, and the increase in circularity can be seen. The tension produced radial and concentric splitting of the fiber wall. Fibers tensioned in the dry state showed no apparent change in cross-sectional area and circularity.

The change due to tensioning was not instantaneous, bundles embedded without a period of tensioning in water showing smaller increases in area and circularity for a given load. Prolonging the tension to 75 hrs. did not increase the change brought about after 1 hr. of tensioning.

If the fibers were allowed to dry either with or without tension applied, the area and circularity decreased to levels below those obtaining in the wet-tensioned state. In attempts to block this reversion by formaldehyde cross-linking during the wet-tensioning, rupture of the bundles invariably occurred.

Swelling in Other Media

In Table II are shown results obtained on fibers stretched in reagents believed to plasticize the cellulose of cotton. Immersion in these reagents without tension produced apparently permanent increases in fiber cross-sectional area, even after removal of the reagent and drying. The sodium hydroxide solution, which mercerized the fibers, brought about the largest increase. When tension was applied, these increases were reduced; in ethylamine, the cross-sectional area of the fibers became as small as that of the untreated sample. The circularity of the fibers was increased by treatment without tension in these reagents, particularly with sodium hydroxide, and these increases became significantly greater as a result of tensioning.

Elongation

The elongation of the fiber bundles under 0.45 g./grex load in the various liquids is outlined in Table III. This table gives the percentage elongation of the bundles after equilibrium had been established following each step of the process of immersion, loading, removal of reagent, drying, and removal of load. It is noted that the dry fiber bundles elongated 3.6%, of which 2.4% was permanent set. After water-stretching and drying, the increase in length remaining after removal of the load was 2.9% more than that of the dry bundles. In 50% urea, a behavior similar to that of the dry bundle was observed. In a parallel experiment, in which a small amount of wetting agent was added to the urea solution, the elongation behavior was more like that of the water-stretched bundle. In ethylamine, a definite stretch occurred on removal of the reagent with chloroform, which was recovered on removal of the load after drying. The mercerizing-strength sodium hydroxide allowed the greatest increase in length

TABLE III. PERCENTAGE ELONGATION OF COTTON FIBER BUNDLES

Treatment	In liquid	Reagent removed*	Dried*	Unloaded
Dry	—	3.6	—	2.4
Water	0	5.3	—	5.3
50% urea (no wetting agent)	0.8	3.7	3.2	3.1	2.7
50% urea (wetting agent)	1.8	5.7	5.7	5.7	5.7
Ethylamine	1.5	4.6	5.6	5.6	4.7
18% sodium hydroxide	0	3.5	6.5	6.5	6.5

* Under tension of 0.45g./grex.

under load, and, like the water-stretched bundle, this was retained after drying and load removal. The contraction in length usually observed on placing fibers in such reagents did not occur, presumably because of the slight tension initially placed on the bundle to provide sufficient stability for observations. In every case, the elongation introduced by tensioning in the reagent exceeded that produced in the dry bundle.

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Heat-Resistance of Partially Acetylated Cotton Fabrics

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THE PHYSICAL AND CHEMICAL properties of the fibers in cotton fabrics are altered by partial acetylation. The cotton thus chemically modified has different dyeing characteristics [5], increased electrical resistance [6], more resistance to attack by microorganisms [4], and an increased ability to withstand heat [1, 2, 5]. The last characteristic mentioned is particularly important to many end-uses of cotton. Practical-use tests have shown that the heat-resistance of a partially acetylated cotton is greater than that of the untreated fabric. The present investigation was undertaken to evaluate the influence of heat on partially acetylated cotton fabrics as compared with an unacetylated control of the same original material. Comparisons were made of the effect of heating the fabrics at a temperature of 160°C in an inert atmosphere of dry nitrogen, in dry air, in water vapor, and in a mixture of air and water vapor.

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Fabrics

After desizing and scouring a gray commercial cotton sheeting, one portion was set aside for use as the unacetylated control and three other portions were acetylated to three different degrees by the improved method of Goldthwait *et al.* [2, 4]. For convenience, the fabrics were coded as follows: U, unacetylated; A–1, 17.4% acetyl (equivalent to 0.8 acetyl group per glucose unit); A–2, 23.4% acetyl (equivalent to 1.1 acetyl groups per glucose unit); A–3, 28.7% acetyl (equivalent to 1.5 acetyl groups per glucose unit).

A length of 66 in. from each of the four fabrics was sampled in such a manner as to minimize the effect of any nonuniformity of the fabric: Starting 4 in. in from the selvage, twenty strips 1½ in. wide were cut down the 66-in. length and were raveled to 48 warp threads. Each strip was cut into 6-in. lengths, and the resulting 220 specimens were code-marked to identify their original positions in the whole fabric. The first, sixth, and eleventh specimens

from each strip (60 specimens) were reserved for testing to establish the values of selected properties of the fabrics before subjection of other specimens to the various test conditions. The specimens from the intermediate positions were separated into odd-numbered and even-numbered strips, thus obtaining 16 sets of 10 specimens each. Sets of even- or odd-numbered strips were chosen for any one test condition so that the same warp threads were involved in each experiment for that particular condition. In addition, 3-in. squares were cut with a die from random positions on each of the fabrics.

After conditioning for at least 24 hrs. at 65 ±2% relative humidity and 70° ±2°F, the following properties were determined for each of the 4 fabrics before heating: breaking strength and elongation at break on a pendulum-type tester; weight, thread count, and thickness by A.S.T.M. procedures; percentage of acetyl by the Eberstadt method [3]; percentage of moisture regain by drying in a forced-draft oven for 5 hrs. at 105°C; and percentage of crimp of warp threads from the stress-strain curve obtained by means of an inclined-plane tester, the linear portion of the curve being extrapolated to zero load and the intercept on the elongation axis converted to percentage of crimp.

The data obtained for the unheated fabrics show the effect of acetylation on the various properties determined (Table I). The warp thread count, of course, changed proportionately with fabric width. As the degree of acetylation increased, the percentage of crimp of warp threads, the thickness, and the weight increased, and the filling thread count showed a tendency to increase. The magnitude of these changes was undoubtedly partially dependent upon the method of handling the fabric in processing. During the acetylation step, the fabric had been allowed to shrink widthwise and was stretched back to approximately the original width while drying on the tenter frame. It can be assumed that the more extensive the acetylation process, the greater the shrinkage. Therefore, during drying, when the tension on the filling threads was considerable and that on the warp threads at a minimum, it would be expected that the filling threads would be brought closer together and that the warp threads would develop a greater crimp. This most probably would also contribute to the increase in thickness of the fabrics.

It is possible to calculate the weights of the acetylated fabrics from that of the unacetylated by taking into account the percentage of acetyl added and the changes in the moisture regain, thread count, percentage of crimp in the warp threads, and fabric width. The values so obtained are: A–1, 498; A–2, 5.38; A–3, 6.01 oz. per sq. yd. The differences between these calculated weights and the weights as determined experimentally are 3% or less, which is within the limits of experimental error.

The breaking strengths as determined on 48 warp threads showed a tendency to increase as the degree of acetylation increased. However, this did not take into account the change in the thickness of the fabrics. On the basis of unit cross-sectional area of the strips, the tensile strengths of the acetylated fabrics were less than those of the unacetylated by 11.2%, 11.6%, and 13.3%, respectively. Thus, it seems that while the breaking strength increased as the acetylation increased, the tensile strength of the strips decreased.

The percent moisture regain of each acetylated fabric under standard conditions was approximately one-half that of the unacetylated control. However, if the increase in weight caused by acetylation is taken into account and the moisture is calculated as percentage of cellulose content, the series becomes: U, 5.9%; A–1, 4.0%; A–2, 3.7%; and A–3, 3.8%. Therefore, in this range of acetylation and at stand-

TABLE I. PROPERTIES OF THE TEST FABRICS BEFORE HEATING

Property	No. of tests	Unacetylated fabric U	Acetylated fabrics A-1	A-2	A-3
Acetyl (% of dry weight)	2	0.0	17.4	23.4	28.7
Breaking strength (lbs.)	60	57.5	57.0	59.2	63.4
Elongation at break (%)	60	7.5	7.6	8.1	10.6
Weight (oz./sq. yd.)	16	4.24	5.00	5.31	5.83
Thread count (W × F)	10	49.8 × 44.3	49.0 × 45.1	49.1 × 45.2	48.8 × 47.4
Thickness (in.)	26	0.0122	0.0134	0.0140	0.0152
Crimp (%)	10	0.8	2.0	2.9	4.0
Fabric width (in.)	10	38.31	38.95	38.99	39.33
Moisture (% of dry weight)	2	5.9	3.3	2.8	2.7

ard conditions, the acetylated fabrics held approximately two-thirds the weight of water per cellulose residue as compared with the unacetylated fabric.

Conditions of Heating

The specimens were heated in a vacuum oven at 160° ± 4°C (320°F) and at a pressure a few millimeters above atmospheric pressure in four different surrounding media and for different periods of time. The oven was evacuated to remove as much air as possible before the introduction of the different atmospheric media. Ten specimens from each fabric were heated simultaneously and continuously for each selected time period. In two instances, duplicate experiments were run.

The specimen rack, which slipped into the oven, was fitted with five rows of clips. The specimens, held at the extreme end, hung freely without touching the oven walls at any point. For each experiment, ten 6-in. strips and one 3-in. square from each fabric were clipped to the frame so that the forty strips formed four rows from the front to the back of the oven and the squares formed the center row. Any effect due to the position of each specimen in the oven was canceled by placing the strips of any one fabric in the same positions for all experiments—*i.e.*, on diagonals from left front to right rear.

Condition I

Immediately after the samples were placed in the preheated oven, the oven was evacuated and then filled with dry, oxygen-free nitrogen. This was obtained by passing commercial oil-pumped nitrogen through a tube containing heated copper turnings and then through an efficient drying tower. The evacuation was repeated, and finally the valves were set to permit a fairly rapid flow of nitrogen through the oven under a head of 1–2 mm. of mercury throughout the heating period.

Condition II

The same procedure was used but, instead of nitrogen, compressed air was filtered through a tube of loose cotton and then passed through the drying tower into the oven.

Condition III

Water vapor was used instead of nitrogen. A flask of air-free distilled water, electrically heated to a smooth boil, furnished the water vapor for this condition. The steam generated passed through a heating tube before entry into the oven. A safety trap was added to the outlet side of the oven to prevent the air from being drawn back into the oven.

Condition IV

A mixture of water vapor and air (approximately 50-50 by volume) was substituted for the nitrogen. The compressed air was passed through the tube of loose cotton and bubbled through the boiling water in the flask. The resulting mixture of air and water vapor then continued on through the heating tube into the oven. At intervals during the experiment, samples of the mixture were withdrawn and analyzed to control the proportions of air and water vapor.

At the end of the heating period, the specimens were conditioned for 24 hrs. at 65 ±2% relative humidity and 70° ±2°F, and various properties were redetermined. The weights and thicknesses of the 3-in. squares were compared with the values obtained on these individual specimens before heating. The broken strips and squares were then used for the determinations of percent acetyl and percent moisture regain.

Results of Heating

Although there are several tests of varying sensitivity whereby the degradation of cellulose can be measured, the breaking strength was selected as the criterion for this study because of its practicability.

In Table II are listed the average breaking strengths and elongations at break after heating in the four different atmospheres for different periods of time. The breaking strength of the unacetylated fabric, in the individual experiments, decreased more than that of any of the acetylated fabrics. Since the average breaking strengths of the four original unheated fabrics are different, the breaking strengths after heating are more easily compared if plotted as percentage of strength retained against time of heating (Figure 1). There was no significant difference between the values for the three fabrics of different degrees of acetylation after any individual heating period.

The breaking strengths retained by the unacetylated fabric after 48 hrs. heating under the four conditions showed that the combined effect of heat and air (condition II) was twice as great, and that of heat and water vapor (condition III) more than three times as great, as that of heating in an inert

TABLE II. AVERAGE BREAKING STRENGTHS (LBS.) AND ELONGATIONS AT BREAK (IN.), WITH STANDARD DEVIATIONS *

Time of heating (days)	No. of breaks	Unacetylated fabric U	Acetylated fabrics A-1	A-2	A-3
		Control values			
0	60	57.5 ± 2.8 *0.224 ± 0.018*	57.0 ± 2.2 *0.299 ± 0.011*	59.2 ± 2.6 *0.242 ± 0.008*	63.4 ± 2.7 *0.318 ± 0.015*
		Condition I—Atmosphere of dry, oxygen-free nitrogen			
2	10	43.8 ± 2.2 *0.173 ± 0.021*	56.3 ± 1.6 *0.212 ± 0.011*	57.7 ± 2.9 *0.239 ± 0.010*	63.7 ± 1.7 *0.323 ± 0.013*
4	10	40.3 ± 2.9 *0.161 ± 0.015*	56.5 ± 1.9 *0.209 ± 0.011*	57.0 ± 1.6 *0.238 ± 0.009*	61.8 ± 3.9 *0.314 ± 0.021*
		Condition II—Atmosphere of dry air			
2	10	31.3 ± 1.2 *0.133 ± 0.016*	53.7 ± 1.7 *0.210 ± 0.011*	56.8 ± 2.2 *0.242 ± 0.008*	59.5 ± 3.0 *0.298 ± 0.024*
4	10	16.8 ± 1.1 *0.096 ± 0.016*	45.7 ± 3.2 *0.183 ± 0.012*	46.2 ± 2.7 *0.203 ± 0.013*	49.1 ± 3.9 *0.278 ± 0.010*
7	10	13.1 ± 1.3 *0.108 ± 0.020*	38.9 ± 2.9 *0.180 ± 0.009*	37.2 ± 3.4 *0.188 ± 0.012*	39.2 ± 3.3 *0.264 ± 0.013*
		Condition III—Atmosphere of water vapor			
1	20	17.2 ± 3.0 *0.111 ± 0.022*	55.6 ± 2.5 *0.233 ± 0.006*	55.7 ± 2.9 *0.242 ± 0.014*	60.7 ± 3.2 *0.339 ± 0.008*
2	10	10.6 ± 0.9 *0.083 ± 0.023*	54.6 ± 2.3 *0.226 ± 0.008*	54.5 ± 2.1 *0.236 ± 0.011*	58.3 ± 3.3 *0.313 ± 0.020*
		Condition IV—Atmosphere of water vapor and air (approximately 50-50 by volume)			
1/4	20	35.0 ± 3.6 *0.166 ± 0.023*	55.3 ± 3.5 *0.219 ± 0.011*	54.2 ± 5.0 *0.238 ± 0.027*	59.7 ± 4.1 *0.326 ± 0.017*
1	10	17.1 ± 1.6 *0.113 ± 0.012*	54.0 ± 1.8 *0.201 ± 0.002*	54.8 ± 2.4 *0.214 ± 0.012*	60.4 ± 2.1 *0.297 ± 0.016*
2	10	9.7 ± 1.3 *0.091 ± 0.025*	52.5 ± 2.2 *0.199 ± 0.017*	50.1 ± 2.8 *0.210 ± 0.021*	54.4 ± 3.3 *0.314 ± 0.014*

* The 3-in. gage warp strips, raveled to 48 threads, were heated at 160°C in different atmospheres for varying periods of time, and were then conditioned for 24 hrs. at 65% R.H. and 70°F before being broken. Values for elongations at break are in italics.

atmosphere (condition I). The combination of heat, water vapor, and air (condition IV) did not produce a significant difference from the effect of condition III.

For any of the acetylated fabrics, the effect of heat alone—*i.e.*, in nitrogen—at 160°C was small, amounting to less than 5% loss in strength even after 4 days of continued heating, as compared with a

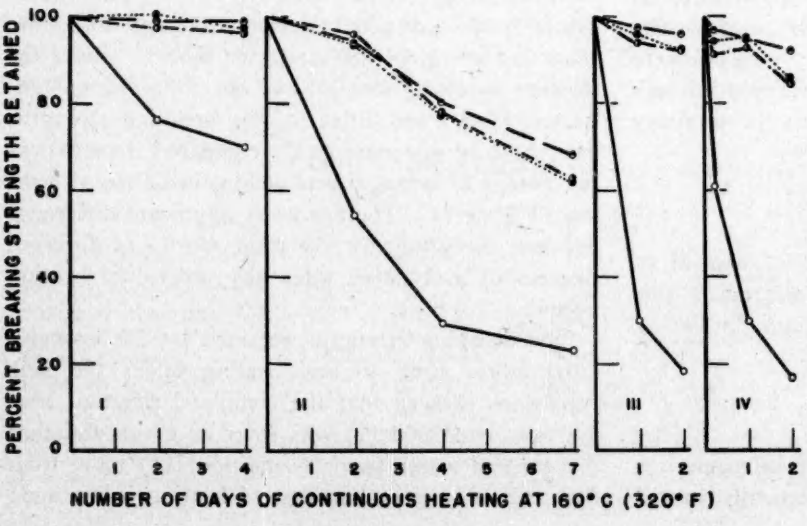

FIG. 1. *Percentage of breaking strength retained* vs. *number of days of continuous heating at 160°C under the four different conditions:* I, *dry, oxygen-free nitrogen;* II, *dry air;* III, *water vapor;* IV, *mixture of water vapor and air.* ○—○, *unacetylated (U);* ◓– –◓, *17.4% acetylated (A–1);* ◑·—·◑, *23.4% acetylated (A–2);* ●....●, *28.7% acetylated (A–3).*

30% loss of the unacetylated fabric. However, the addition of air (condition II) produced a 20% decrease after 4 days of heating, as compared with 70% for the unacetylated fabric. The effect on the acetylated fabrics of the different atmospheres in the heating chamber is shown by a comparison of the losses in breaking strength after heating for 2 days under the four conditions. In an inert atmosphere, the loss was less than 3%, in air 4%–7%, in water vapor 4%–8%, and in a mixture of air and water vapor 8%–16%. The corresponding losses for the unacetylated fabric were 24%, 46%, 82%, and 83%.

In general, the elongation at break was less as the breaking strength decreased. The unacetylated fabric lost a greater percentage of its elongation after heating than any of the acetylated fabrics, an observation comparable to that made in the breaking-strength analyses. A plot of percentage loss in elongation at break against time of heating resulted in a graph quite similar to Figure 1. Furthermore, if each percentage of loss in breaking strength was plotted against its percentage of loss in elongation at break, a correlation was observed, in spite of the scattering of points, from which it was estimated that a 1% loss in breaking strength was accompanied by approximately 0.75% loss in elongation at break.

The changes in the other physical properties after heating and reconditioning were consistent, but too small to be truly significant. These included a loss in weight and an increase in thickness of all fabric specimens, as shown by a comparison of the measurements on the 3-in. squares before and after heating. In addition, there was a tendency in the acetylated fabrics for the warp thread count to increase.

Heating under any of the four conditions did not produce a change in the percentage of acetyl as determined by the Eberstadt method. After heating, all fabrics maintained the same percentages as the unheated specimens. Therefore, it may be concluded that the heating conditions did not drive off a significant number of acetyl groups, nor was there any transfer of acetyl groups from the acetylated to the unacetylated specimens in the oven.

The percent moisture regain was less after heating at 160°C, being approximately ½% less for the acetylated specimens and approximately 1% less for the unacetylated.

Summary

Partially acetylated fabrics were found to be definitely more heat-resistant than the corresponding unacetylated fabric. This was demonstrated by heating specimens of commercial sheeting, unacetylated and acetylated to contain 17.4%, 23.4%, and 28.7% acetyl, at a temperature of 160°C (320°F) in dry, oxygen-free nitrogen, in dry air, in water vapor, and in a mixture of water vapor and air for varying periods of time. The resultant loss in breaking strength was indicative of the relative ability of the different fabrics to withstand heat.

The acetylated fabrics retained a greater percentage of their original breaking strengths than the unacetylated fabric under each condition. The effect on the acetylated fabrics of the different atmospheres in the heating chamber was shown by a comparison of the losses in breaking strength after heating for 2 days under the four conditions. In nitrogen, the loss was less than 3%, in air 4%–7%, in water vapor 4%–8%, and in air and water vapor mixture 8%–16%. The greater degradation of the unacetylated control is reflected in the corresponding losses of 24%, 46%, 82%, and 83%. The losses in elongation at break tended to parallel the losses in breaking strength.

No measurable quantity of acetyl was lost from the acetylated fabrics during heating. After heating and reconditioning, all the fabrics showed a slight decrease in weight and in percentage of moisture regain, and a slight increase in thickness.

Acknowledgment

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INDUSTRIAL SECTION

A Comparative Study of Sonic and Mechanical Home Washers

Part I: Strength and Dimensional Changes*

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FOR CENTURIES, textile fabrics have been laundered by the application of some type of mechanical action in a water medium. Mechanical action has varied from pounding fabrics with rocks in streams to oscillating or twirling fabrics in the modern automatic home or commercial laundry equipment.

The need for providing some means of bringing the detergent solution and the cloth undergoing laundering into more intimate and efficient contact than that provided by gross mechanical action, with a greater preservation of the strength of the fabric, has encouraged research workers to study other methods, such as sending acoustical waves through the detergent medium, with results which have given promise of having practical applications.

Schilling, Rudnick, Allen, Mack, and Sherrill [2] began studies in this field in 1947, using a high-frequency siren, equipment described by Allen and Rudnick [1]. These authors were the first to publish numerical data in this country on the subject of sonic and ultrasonic waves as a means of removing soil from textile fabrics. In the work of these investigators, the amount of detergent used was that found previously to be optimum in studies with power laundry machinery. Data were presented to show that 1,000 min. of total washing time and 50 changes of soap and water produced about 80% as much soil removal as 60 min. of exposure in a water-soap medium to an intense sound beam. Moreover, the 60-min. treatment with the siren gave as good or better soil removal than that obtained by three excellent commercial laundries, each using 50 complete washing cycles and a total washing time of 3,500 min.

In the spring of 1950, a laboratory model of a small home sonic washing device invented in Australia became available for study in the Ellen H. Richards Institute. The device operated at a considerably lower frequency than was used in the laboratory sonic and ultrasonic studies previously begun in these laboratories, and was described by the inventor as being equal to or superior to the most widely used mechanical home washing machines in soil removal.

The possibility of strength conservation and resistance to dimensional change in textile fabrics by the use of acoustical waves suggested a comparative study of these factors, in addition to an evaluation of soil removal with the new instrument in comparison with customary methods of washing.

* This is the first report on the sonic washing of rayon fabrics, sponsored by American Viscose Corporation through a fellowship at the Ellen H. Richards Institute, School of Chemistry and Physics, The Pennsylvania State College.

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The present report compares the strength and dimensional changes brought about by laundering rayon fabrics by means of the laboratory-model sonic washer with results of laundering by hand and of laundering with a home automatic washer of a type in wide use in this country. Soil removal and other comparative data will be published in a later report.

For a comparison of the results obtained with the sonic washer and with washing by hand, six rayon fabrics were used, including a Salyna (fabric 1), two gabardines (fabrics 2 and 4), a poplin (fabric 3), a dull-luster taffeta (fabric 5), and a very lightweight satin (fabric 6). These represented a weight range from 5.6 to 2.5 oz. per sq. yd., four major weave types, spun and filament yarns, and three fiber types.

For comparative trials of strength and dimensional changes effectuated by the experimental sonic washer and the conventional home automatic washing machine, fabric 1 (salyna), fabric 2 (gabardine I), and fabric 3 (poplin) were selected.

None of the fabrics in the study had received treatment during manufacture designed to stabilize the dimensions.

Plan of Procedure

Washing Equipment

Sonic Washer.—The laboratory model of sonic washer used in the study, called an Electro-Sonic washer, is a low-frequency device in which 60-cycle power is supplied to an electromagnetic motor producing 120-cycle vibrations of a diaphragm and housing.

Each time the electric current passes through the winding in the electromagnetic motor, a magnetic field is set up in the magnetic core, and the armature spring returns to its normal position. As the electric current builds up in the winding again, the magnetic field is set up again, and the armature spring is attracted upward and then released. Since there are 60 such cycles per sec., there is a magnetic field followed by a null setup 60 times per sec. This causes the armature spring to move up and down 120 times per sec. These up and down movements, or vibrations, exert a force resulting in sound waves. The sound waves are 40 ft. long, and move at a speed of 5,000 ft. per sec. This rapid reciprocating force is the factor which pushes the soil from fabrics.

The sonic washer has a handle at the top for lifting it into and out of the water bath. It weighs 7½ lbs., and operates on A. C. 100-v. electric current.

Comparative Equipment.—Comparisons of strength and dimensional changes in rayon fabrics washed in the sonic washer were made with results obtained on the same fabrics washed in an automatic home mechanical washer. The washer that was used operated at one speed for washing and rinsing, and at a faster speed for removal of water. The washer had a capacity of 8 gals. of water, and a rated wash load of 9 lbs. It was operated with the 9-lb. load. The washing cycle was that adopted for the sonic washer.

Experimental Fabrics

Descriptions of the six experimental fabrics are given in Table I.

The initial and periodic measurements made on the fabrics included: wet and dry breaking strength, by the ravel strip method (warp and filling), using the conventional Scott motor-driven tester; bursting strength, using a Mullen motor-driven tester; and dimensional change, by linear measurement in the two directions of a 10-in. square marked by means of a templet.

Breaking-strength changes were calculated on a per-thread basis.

Washing Procedures

Sonic Washing Treatments.—The sonic washing series, using the experimental home sonic washer, as described, included the following conditions:

Treatment 1 (neutral soap, low temperature): Neutral low-titer (17.8°C titer) soap of 0.05% concentration was used in 20 washings at a temperature of 120°F in zeolite-softened water, each washing consisting of a 10-min. break in water, followed by a 17-min. wash with the designated soap concentration, followed by one 1-min. one 5-min., and one 1½-min. rinse, in sequence. The fabrics were run through a squeeze-type roll wringer for one pass, and were then hung up to air-dry.

The sonic device was in operation throughout the series of steps in the washing cycle, the parts of the series being designed to simulate the cycle for which the automatic home washer was set.

Measurements of strength and dimensional changes were made on the six experimental fabrics used in this washing treatment after 1, 5, 10, 15, and 20 successive launderings.

TABLE I. DESCRIPTIONS OF THE 6 EXPERIMENTAL FABRICS

Specification	Fabric 1 (Salyna)	Fabric 2 (gabardine I)	Fabric 3 (poplin)	Fabric 4 (gabardine II)	Fabric 5 (dull-luster taffeta)	Fabric 6 (satin)
Fiber type	Viscose rayon and cotton	Viscose rayon	Viscose rayon	Viscose rayon and cotton	Viscose rayon	Cellulose acetate rayon
Yarn type	Spun	Spun	Spun	Spun	Filament	Filament
Weave type	Plain (poplin)	Gabardine 2/2 twill	Plain (poplin)	Gabardine 2/2 twill	Plain	5-Shaft satin
Weight per sq. yd. (oz.)	5.6	4.6	3.5	4.8	2.6	2.5
Thread count (threads per in.)						
Warp	50	126	69	121	98	194
Filling	43	68	39	65	73	74
Average twists per inch of yarn						
Warp	11.9* 16.9 31.1	20.0	21.5	23.4† 21.3‡	21.0	1.2
Filling	11.9* 18.8 31.7	18.4	15.4	19.5	3.0	1.5
Filaments per yarn						
Warp	Spun yarn	Spun yarn	Spun yarn	Spun yarn	60	20
Filling	Spun yarn	Spun yarn	Spun yarn	Spun yarn	90	48
Fiber length (in.)						
Warp	1.3† 1.0‡	1.5	1.8	1.3† 1.3‡	Filament yarns	Filament yarns
Filling	1.3† 1.0‡	1.4	1.5	1.4	Filament yarns	Filament yarns
Total yards per pound of yarn ($\times 10^{-3}$)						
Warp	9.6* 13.7 43.3	26.6	25.6	26.7† 28.0‡	44.5	64.9
Filling	10.5* 13.0 47.5	24.0	11.3	24.4	29.2	45.4
Initial breaking strength						
Dry, Warp	53.25	78.10	44.95	70.35	35.3	40.3
Filling	32.2	44.15	63.3	43.9	45.7	20.9
Wet, Warp	27.65	35.25	23.65	46.95	10.2	19.35
Filling	21.1	19.8	29.8	19.8	11.95	9.4
Initial bursting strength						
Dry	124.4	139.6	148.9	153.0	109.5	79.3
Wet	63.9	59.6	76.0	71.6	38.8	47.9

* Three-ply yarn. † Viscose. ‡ Cotton.

Treatment 2 (built soap, low temperature): Alkaline built soap, composed of the same soap as in treatment 1 built with trisodium phosphate (ratio of soap to builder, 2:1), was used at a concentration of 0.05% (based on total weight of soap and builder) in 50 washings at a temperature of 120°F, the washings consisting of the same series as in treatment 1. The fabrics tested were five pieces each of three rayon fabrics.

The same observations were made as in treatment 1 after 1, 5, 10, 15, 20, 30, and 50 launderings.

The concentration of the soap used in washing treatments 1 and 2 was dictated by the fact that 0.05% is the maximum soap concentration which can be used in an automatic home washing machine of the type employed without incurring a suds overflow; because comparisons were desired on the same fabrics washed under the same conditions, except for

the type of mechanical action, this concentration of soap was employed in the two sonic washing treatments.

Gross Mechanical Washing Treatments.—

Hand Washing: The hand washing treatments consisted of a series of 20 repetitions of mild squeezing of the fabrics by hand at 105°F, using neutral soap of the same type and concentration as that in treatment 1, as described above. This involved two 5-min. hand washings in soap and zeolite-softened water, followed by three 2-min. rinsings in distilled water. The mechanical aspects of the hand washing treatments were standardized as nearly as possible.

Automatic Home Washing Machine Treatment: The same neutral low-titer soap as in sonic washing treatment 1 was used, at a concentration of 0.05%. There were 20 washings at 120°F in zeolite-softened water, each washing consisting of a 10-min. break, followed by a 17-min. wash with the designated soap concentration, followed by one 1-min., one 5-min., and one 1½-min. rinse, in sequence. The fabrics were spun in the automatic device, and were air-dried.

A preliminary attempt to continue this series beyond 20 washings showed rapid fabric degradation, particularly of fabric 3. Hence, data for these mechanical washings are reported only through 20 washings.

Findings and Discussion

Comparison of Strength and Dimensional Changes in Fabrics Caused by Laundering with a Home Sonic Washer and by Hand

Table II, Part A, shows the percentage changes in dry and wet breaking-strength values, warp and filling, of the six experimental fabrics when washed by means of the laboratory model of the home sonic washer employed in this study, using neutral soap at 120°F, and by the hand washing treatment, using neutral soap at 105°F, using 0.05% concentration of soap in both cases. Table II, Part B, gives data for dry and wet bursting strength.

Table II, Part C, gives comparable data on the dimensional changes incurred by these two washing methods.

Figures 1 and 2 show the strength changes which occurred through 20 washings when sonic and hand washing were applied to the heaviest- and the lightest-weight of the experimental fabrics, respectively.

The data of Table II and Figures 1 and 2 show that, in the great majority of cases, hand washing for 16 min. at 105°F caused greater strength losses than did sonic washing for 34.5 min. at a higher temperature (120°F). The difference in values for the stronger fabrics was much less than for the weaker fabrics, as Figures 1 and 2 clearly show for fabric 1 (Salyna) and fabric 6 (lightweight satin).

Differences between the two washing techniques were greater in the breaking-strength than in the bursting-strength values, with breaking-strength differences in the warp being greater than those in the filling direction. The fabric showing the greatest spread between the hand washing and the sonic washing strength values after repeated washings was fabric 3 (poplin).

With respect to dimensional change in these non-stabilized fabrics, results generally did not differ markedly between the sonic washing and the hand washing by a squeezing (not a rubbing) action, although in some cases the sonic treatment caused somewhat greater shrinkage.

Comparison of Strength and Dimensional Changes in Fabrics Caused by Laundering with a Home Sonic Washer and a Home Automatic Washing Machine

Table III, Part A, gives the changes in dry and wet breaking strength; Part B, in dry and wet bursting strength; and Part C, in linear dimensions which occurred in fabric 1 (Salyna), fabric 2 (gabardine I), and fabric 3 (poplin) when they were laundered, respectively, with the sonic washer and the automatic home washer using neutral soap through 20 successive washings, and with the sonic device using built soap through 50 repeated launderings.

Bar graphs show breaking-strength changes (Figure 3) and bursting-strength and dimensional changes (Figure 4) in these three fabrics.

Breaking-Strength Changes During Washings with Neutral Soap.—Figure 3 shows that the changes in dry warpwise breaking strength as occasioned by the sonic and the automatic home washers operating under the same conditions (temperature, 120°F; neutral soap of 0.05% concentration) except for type of washer, were similar for the heaviest fabric of firm, plain-weave construction (fabric 1). The changes for the gabardine fabric (fabric 2) were far less with the sonic than with the gross mechanical washing device. After 10 washings, the sonic device had caused a loss of 8.5% (as compared with the

TABLE II. PERCENTAGE CHANGE IN STRENGTH AND LINEAR DIMENSIONS OF 6 EXPERIMENTAL FABRICS LAUNDERED WITH THE HOME SONIC WASHER AND BY HAND*

Part A—Percentage Dry and Wet Breaking-Strength Change

Fabrics and treatments	After 1 laundering				After 5 launderings				After 10 launderings				After 15 launderings				After 20 launderings			
	Dry		Wet		Dry		Wet		Dry		Wet		Dry		Wet		Dry		Wet	
	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling
Fabric 1 (Salyna)																				
Sonic washing	− 4.6	+ 8.5	− 4.0	− 5.4	− 3.8	− 1.2	− 0.1	− 3.4	− 7.5	−12.4	−10.4	− 7.5	−10.0	−10.0	− 1.5	−10.9	− 9.4	− 6.0	−10.8	−12.8
Hand washing	− 3.2	−10.4	− 7.1	−14.3	− 8.4	− 7.9	− 9.9	−11.0	−10.8	−13.7	−12.9	−17.7	− 6.0	− 6.5	−10.9	− 5.1	−11.6	− 4.0	−12.9	− 3.8
Fabric 2 (gabardine I)																				
Sonic washing	−14.7	− 8.6	+15.8	− 3.6	−16.1	− 4.1	+10.6	− 2.3	− 8.5	− 6.8	− 4.9	+ 1.3	−25.2	− 1.6	− 2.4	+ 9.5	−16.4	− 5.3	+ 6.9	+ 1.0
Hand washing	− 4.1	− 1.4	−21.3	− 0.5	−10.4	− 3.7	−29.1	− 5.0	−25.1	− 1.8	−28.6	− 6.9	−24.9	− 7.2	−42.0	−10.4	−22.0	− 2.1	−37.9	−11.4
Fabric 3 (poplin)																				
Sonic washing	+ 5.3	−12.1	+ 1.7	− 2.4	− 2.6	− 8.3	− 3.4	−12.3	− 2.9	−11.4	− 7.2	− 1.1	−15.2	− 3.0	− 7.8	+ 5.5	− 2.1	−13.6	−11.5	− 0.2
Hand washing	− 7.9	+ 2.9	−20.2	+ 6.5	−18.7	+ 7.2	−34.5	+17.3	−34.7	+ 7.1	−43.8	+ 3.2	−45.7	+ 6.0	−52.3	+16.2	−35.3	+16.4	−52.3	+14.4
Fabric 4 (gabardine II)																				
Sonic washing	− 3.8	− 4.9	+18.5	+20.0	+ 5.3	0.0	+21.2	+20.0	− 0.2	+ 1.6	+22.4	+27.6	− 7.3	+ 2.4	+16.6	+18.7	− 4.6	+ 8.1	+31.0	+25.0
Hand washing	− 4.9	+ 4.4	−13.0	+16.9	− 9.8	+ 7.3	− 7.8	+12.7	+ 2.5	+ 9.0	−14.6	+12.2	− 0.5	+ 4.6	−13.8	+34.4	− 5.1	+ 6.1	−24.6	+ 7.4
Fabric 5 (dull-luster taffeta)																				
Sonic washing	− 9.5	−15.5	0.0	0.0	−15.6	− 3.0	− 5.8	+26.0	0.0	− 1.4	+ 1.0	+15.0	− 8.9	−12.4	− 4.8	+ 3.0	− 4.2	+ 0.3	− 5.8	+12.0
Hand washing	−10.8	−10.2	− 1.1	− 3.2	− 1.9	+ 6.0	−11.2	− 2.4	− 0.7	+ 4.5	−13.5	+ 7.1	+ 6.3	+16.5	−12.4	− 4.8	+ 9.3	+15.9	−18.0	+ 1.6
Fabric 6 (satin)																				
Sonic washing	− 3.0	− 7.0	+11.5	+ 7.8	− 9.0	− 1.0	+13.5	+11.7	0.0	− 0.7	+ 6.2	+10.9	− 9.5	− 5.6	+ 9.4	+ 8.6	− 4.0	− 1.4	+ 8.3	+ 7.8
Hand washing	−22.0	− 6.5	−19.7	−19.0	−28.5	− 9.7	−19.3	− 9.5	−27.3	− 5.4	−16.0	− 4.8	−42.2	− 7.0	−18.1	−11.4	−40.4	− 9.7	−35.4	−15.2

* Temperature, 120° F for the sonic and 105° F for the hand washing, respectively; neutral soap; soap concentration, 0.05%.

TABLE II.—*Continued*

Fabrics and treatments	*Part B—Percentage Dry and Wet Bursting-Strength Change*										*Part C—Percentage Change in Linear Dimensions*									
	After 1 laundering		After 5 launderings		After 10 launderings		After 15 launderings		After 20 launderings		After 1 laundering		After 5 launderings		After 10 launderings		After 15 launderings		After 20 launderings	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling
Fabric 1 (Salyna)																				
Sonic washing	− 6.4	+ 3.6	− 1.8	+10.3	+ 8.3	+ 9.2	+ 2.7	+12.5	+ 2.9	+12.3	− 1.9	− 3.3	− 2.9	− 2.1	− 4.9	− 2.3	− 5.3	− 2.4	− 4.6	− 2.4
Hand washing	+ 5.8	+ 7.2	+ 4.6	+12.8	+11.1	+16.2	+ 6.6	+11.5	+ 6.4	+12.5	− 1.5	+ 1.0	− 2.8	+ 1.5	− 3.6	+ 2.1	− 3.7	+ 1.7	− 4.7	+ 3.3
Fabric 2 (gabardine I)																				
Sonic washing	+10.5	− 8.9	+ 1.4	−11.0	− 7.7	−16.1	− 5.5	−12.6	+ 5.4	−11.4	−11.2	− 3.7	−13.4	− 2.1	−14.6	− 3.8	−15.6	− 2.6	−16.2	− 2.7
Hand washing	− 6.4	− 1.3	+ 1.5	− 2.1	− 4.8	− 6.9	− 9.6	−18.0	− 3.5	−16.9	− 8.2	+ 0.6	− 9.7	+ 1.4	−10.7	+ 2.9	−11.6	+ 1.5	−12.5	+ 1.0
Fabric 3 (poplin)																				
Sonic washing	+ 8.0	+ 9.0	+ 2.5	−15.0	− 7.2	−11.5	+ 7.3	− 8.5	+ 5.2	− 5.5	− 9.4	− 2.9	− 9.9	− 0.6	−10.3	− 0.9	−14.4	− 2.3	−11.8	− 1.6
Hand washing	− 1.2	− 2.3	− 2.7	− 8.6	− 3.4	−13.8	− 9.1	−19.9	−11.1	−26.2	− 3.6	+ 3.3	− 6.3	+ 3.5	−10.7	+ 4.1	− 9.4	+ 5.1	−12.6	+ 5.4
Fabric 4 (gabardine II)																				
Sonic washing	+ 5.7	+ 9.2	+ 4.3	+ 8.6	−15.7	+ 8.2	+ 3.9	+ 7.6	+ 6.0	+ 6.8	− 3.1	− 2.1	− 1.9	− 0.8	− 3.1	− 0.8	− 5.1	− 1.2	− 5.5	− 1.6
Hand washing	+ 4.8	− 2.3	+ 3.0	− 6.5	+ 0.8	− 3.6	− 0.6	− 0.9	− 5.2	−10.1	− 1.6	+ 2.3	− 2.6	+ 3.5	− 3.2	+ 4.9	− 3.0	+ 4.5	− 4.3	+ 4.7
Fabric 5 (dull-luster taffeta)																				
Sonic washing	+ 8.5	− 6.3	+11.1	− 9.0	+ 1.7	−21.1	+14.5	−16.6	−12.3	−15.5	− 6.0	− 5.4	− 5.8	− 3.3	− 6.8	− 3.2	− 8.0	− 7.7	− 7.6	− 1.8
Hand washing	− 7.6	− 9.4	+ 9.0	− 8.2	+ 5.3	− 9.7	+ 3.4	−23.9	+ 4.6	+ 4.3	− 2.4	+ 0.9	− 3.0	+ 1.5	− 4.4	+ 1.2	− 3.5	+ 2.2	− 4.5	+ 2.3
Fabric 6 (satin)																				
Sonic washing	− 2.5	− 9.9	+ 2.8	+ 5.2	+ 1.5	− 7.2	+ 5.5	− 6.5	+14.4	− 5.6	− 2.3	− 2.3	− 2.3	− 2.2	− 3.3	− 2.3	− 3.5	− 2.5	− 3.7	− 2.6
Hand washing	− 0.8	−11.3	− 0.8	− 6.8	− 1.1	−10.4	− 3.6	− 8.8	− 4.1	− 6.8	− 0.2	+ 1.2	− 2.3	+ 0.8	− 3.3	+ 0.4	− 3.7	+ 1.7	− 4.6	+ 0.4

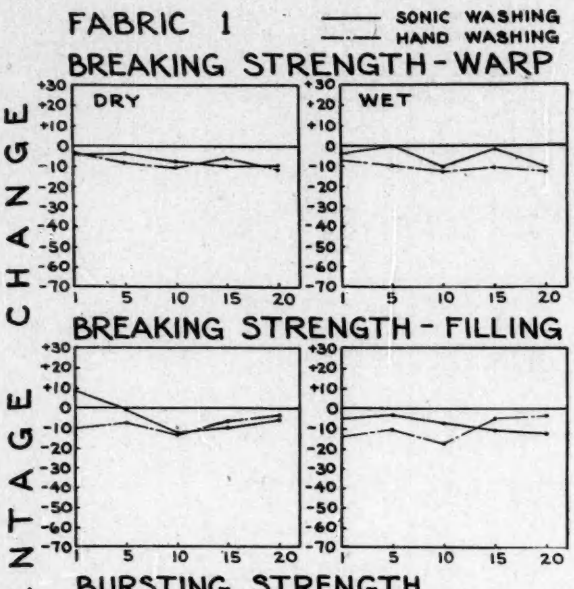

FIG. 1. *Comparative strength losses sustained by fabric 1, the heaviest fabric of the series, during hand washing at 105°F and sonic washing at 120°F, with the same soap type and concentration in both cases. The over-all washing time of each hand washing was 16 min., and that of each sonic washing was 34.5 min.*

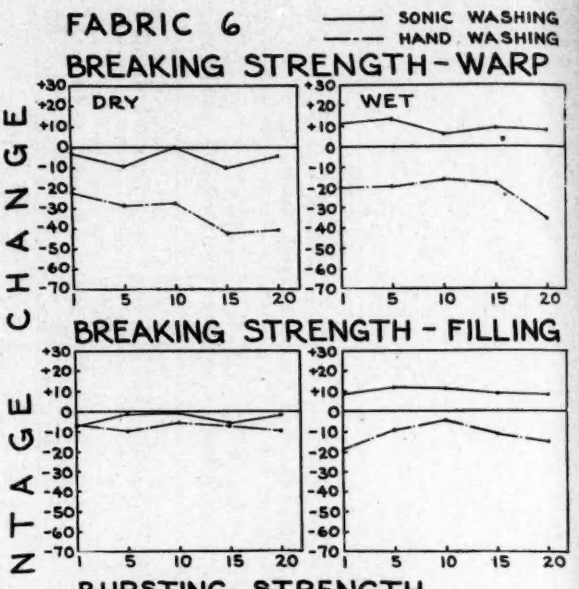

FIG. 2. *Comparative strength losses sustained by fabric 6, the lightest-weight fabric, during hand and sonic washing, respectively, under the conditions outlined under Figure 1.*

initial dry warpwise breaking-strength of the fabric), whereas the automatic home washing machine had incurred a loss of 34.2%. After 20 washings, the losses were 16.4% for the sonic, and 48.0% for the automatic home washer.

The values spread apart still further with the most poorly constructed of the three fabrics (fabric 3, poplin). After only one washing, the sonic device had caused no loss in the dry warpwise breaking strength of this fabric, whereas the automatic home washer had incurred a loss of 11.9%. After 5 washings, the breaking-strength losses incurred by the sonic and by the conventional home automatic washing procedures were 2.6% and 38.6%, respectively; after 10 washings, 2.9% and 50.5%, respectively; and after 15 washings, 15.2% and 56.6%, respectively. At the close of the twentieth washing with neutral soap, the dry warpwise breaking-strength loss was 2.1% for the sonic and 58.4% for the automatic home washer.

The wet warpwise breaking-strength losses were slightly greater in the home mechanical washing series than in the sonic washing series with the strongest of the three fabrics, and were far greater with the other two fabrics.

The strongest, best constructed fabric (fabric 1) showed only small fillingwise breaking-strength changes during the launderings with neutral soap, regardless of the washing device used. Although this fabric, in common with the others, had not been stabilized during manufacture, it shrank less than the other two used in this series of trials, and hence did not show the same strength behavior in the filling direction.

Fabrics 2 and 3 showed some gains in the breaking strength of the filling direction, undoubtedly be-

cause of the tendency toward excessive shrinkage in the warp direction in these two fabrics, which tended to crowd the filling threads together.

Even though the breaking-strength changes were calculated on a per-thread basis, the crowding together of the filling threads resulting from warp shrinkage caused a binding action which negated losses which might otherwise have occurred. Since the warp shrinkages were less in the sonic than in the automatic home washing machine series, fillingwise breaking-strength changes were less with the latter device. In fact, there were filling breaking-strength gains virtually throughout the 20 washings with the conventional type of home washer, and slight gains or slight losses with the sonic device.

Bursting-Strength Changes During Washings with Neutral Soap.—In the bursting-strength measurements (see Figure 4), shrinkages tended to increase the values not only because of an increased binding action, but also because no correction was made for the increased number of threads per unit area of fabric. Therefore, there were no notable differences between the bursting-strength values—dry and wet, fabrics 1 and 2—whether the sonic or the gross mechanical machine was used. In fabric 3, however, the most poorly constructed of the fabrics used in this part of the study, there was a wide spread between the sonic and the automatic home washing machine results on dry and wet bursting strength, in spite of the highly excessive warpwise shrinkage of this fabric. At the close of the 20 washings with neutral soap, the sonic washer had caused a gain of 5.2% in dry bursting strength, as compared with a loss of 34.0% with the automatic home washer. Comparative wet bursting-strength changes were − 5.5% and − 35.0%, respectively.

Dimensional Changes During Washings with Neutral Soap.—Since none of the three fabrics had been stabilized, all showed considerable shrinkage during laundering, with fabric 1 showing the least dimensional change (see Figure 4). Shrinkage warpwise far exceeded the fillingwise shrinkage. Warpwise shrinkage with the sonic washer tended to be considerably less than that with the automatic home washer when neutral soap was used in both operations.

Dimensional changes tended to be small in the filling direction, with no notable differences between the two types of washers with neutral soap as the detergent.

Strength and Dimensional Changes During Sonic Washing with Built Soap.—Continuance of the launderings by the automatic home washer beyond 20 repetitions seemed ill-advised because all except the strongest of the fabrics began to deteriorate rapidly beyond this point.

The excellent strength retention of the fabrics when given 20 successive washings by the sonic washer with neutral soap at 120°F led to another series of 50 washings using built soap. When the strength retention of the fabrics in this series of washings was good at the close of 20 washings, the series was continued through an additional 30 washings, making a total of 50 sonic washings with built soap. The data for this extended washing series are shown in Table III and in Figures 3 and 4.

In fabric 1, the dry breaking-strength loss in the warp direction was only 26.7% after 50 sonic washings with built soap at 120°F. The dry fillingwise breaking-strength loss of this fabric was 14.8%. Wet breaking-strength losses after 50 sonic washings were 18.9% warpwise and 16.0% fillingwise in this fabric. Bursting-strength losses, dry and wet, in fabric 1 after 50 sonic washings were 10.0% and 14.3%, respectively.

In fabric 2, the dry warpwise breaking-strength loss after 50 sonic washings with built soap was 24.0%, as compared with a loss of 48.0% with neutral soap after only 20 washings in the conventional type of washer. The dry fillingwise breaking-strength loss was 10.7% after 50 sonic washings with built soap. The wet breaking-strength losses for this fabric were 13.0% warpwise and 2.0% fillingwise. Bursting-strength losses for fabric 2 were 13.3% in the dry and 16.6% in the wet condition.

Fabric 3 showed a dry warpwise breaking-strength loss after 50 sonic washings with built soap of 24.4%, as contrasted with a loss of 58.4% with neutral soap in the automatic home washer after only 20 launderings. The wet warpwise breaking-strength loss in this fabric was 22.6% in the 50-wash, built soap, sonic washing series, in comparison with 68.2% in the 20-wash, neutral soap, automatic home washing machine series. The dry and wet fillingwise breaking-strength losses in the 50-wash, sonic washing series with built soap were 25.0% and 0.5%, respectively. The bursting-strength losses for this fabric in the series of 50 washings with the sonic washer using built soap were 8.2% dry and 28.0% wet.

TABLE III. Percentage Change in Strength and Linear Dimensions of 3 Experimental Fabrics Laundered with a Home Sonic Washer and with an Automatic Home Washer*

Part A—Percentage Dry and Wet Breaking-Strength Change

Fabrics and treatments	After 1 laundering				After 5 launderings				After 10 launderings				After 15 launderings				After 20 launderings				After 30 launderings				After 50 launderings			
	Dry		Wet		Dry		Wet		Dry		Wet		Dry		Wet		Dry		Wet		Dry		Wet		Dry		Wet	
	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling
Fabric 1 (Salyna)																												
Sonic washing																												
Neutral soap	− 4.6	+ 8.5	− 4.0	− 5.4	− 3.8	− 1.2	− 0.1	− 3.4	− 7.5	−12.4	−10.4	− 7.5	−10.0	−10.0	− 1.5	−10.9	− 9.4	− 6.0	−10.8	−12.8								
Built soap	− 6.6	+ 1.8	+ 3.2	− 4.1	− 9.5	− 3.0	− 1.8	− 6.5	− 0.9	− 8.8	− 4.0	− 8.3	− 8.5	− 7.3	− 0.7	− 6.5	− 8.4	+ 0.1	− 2.2	− 2.2	−15.0	−10.0	− 5.2	− 9.5	−26.7	−14.8	−18.9	−16.0
Washing with automatic home washer																												
Neutral soap	− 5.3	− 3.7	− 8.2	− 8.6	− 5.6	+ 3.0	− 9.3	− 2.1	− 8.1	−12.3	−10.0	−13.3	− 7.5	+ 8.1	−10.3	− 2.6	− 9.2	− 4.2	− 8.5	− 8.2								
Fabric 2 (gabardine I)																												
Sonic washing																												
Neutral soap	−14.7	− 8.6	+15.8	− 3.6	−16.1	− 4.1	+10.6	− 2.3	− 8.5	− 6.8	− 4.9	+ 1.3	−25.2	− 1.6	− 2.4	+ 9.5	−16.4	− 5.3	+ 6.9	+ 1.0								
Built soap	−20.6	− 9.0	− 5.7	0.0	−20.6	+ 0.3	−11.8	− 7.2	−30.2	− 3.7	−23.5	− 3.6	−36.7	−14.5	−10.5	− 7.2	−29.4	−15.7	−15.0	− 5.3	−30.9	−13.9	−10.5	− 4.0	−24.0	−10.7	−13.0	− 2.0
Washing with automatic home washer																												
Neutral soap	+ 3.9	− 2.5	− 6.9	+13.5	−17.5	+ 4.7	−38.5	+ 9.3	−34.2	+19.0	−49.8	+17.3	−39.2	+22.2	−57.8	+13.5	−48.0	−12.7	−64.6	+ 1.9								
Fabric 3 (poplin)																												
Sonic washing																												
Neutral soap	+ 5.3	−12.1	+ 1.7	− 2.4	− 2.6	− 8.3	− 3.4	−12.3	− 2.9	−11.4	− 7.2	− 1.1	−15.2	− 3.0	− 7.8	+ 5.5	− 2.1	−13.6	−11.5	− 0.2								
Built soap	+ 1.3	− 3.8	− 2.5	− 7.5	− 5.2	−10.6	−19.6	− 1.9	−17.0	− 3.0	−22.0	− 4.3	−19.3	−10.6	−33.6	−12.3	−18.1	−19.0	−27.7	− 7.1	−21.6	−36.4	−22.4	− 6.4	−24.4	−25.0	−22.6	− 0.5
Washing with automatic home washer																												
Neutral soap	−11.9	+ 8.6	−19.3	+ 6.5	−38.6	+ 7.1	−51.9	+10.1	−50.5	+22.7	−65.2	+18.6	−56.6	+36.2	−67.4	+18.3	−58.4	+46.9	−68.2	+35.0								

* Temperature, 120° F; soap concentration, 0.05%.

TABLE III.—*Continued*

Fabrics and treatments	*Part B—Percentage Dry and Wet Bursting-Strength Change*														*Part C—Percentage Change in Linear Dimensions*											
	After 1 laundering		After 5 launderings		After 10 launderings		After 15 launderings		After 20 launderings		After 30 launderings		After 50 launderings		After 1 laundering		After 5 launderings		After 10 launderings		After 15 launderings		After 20 launderings		After 30 launderings		After 50 launderings	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling
Fabric 1 (Salyna)																												
Sonic washing																												
Neutral soap	− 6.4	+ 3.6	− 1.8	+10.3	+ 8.3	+ 9.2	+ 2.7	+12.5	+ 2.9	+12.3					− 1.9	− 3.3	− 2.9	− 2.1	− 4.9	− 2.3	− 5.3	− 2.4	− 4.6	− 2.4				
Built soap	+ 2.5	+18.0	+ 2.9	+13.9	− 1.1	− 0.6	0.0	+16.6	+ 1.2	+ 5.2	− 6.0	− 0.2	−10.0	−14.3	− 1.3	− 7.1	− 2.3	−12.2	− 5.0	− 6.8	− 6.2	− 7.5	− 2.8	− 4.3	− 8.5	− 6.3	− 3.2	− 7.1
Washing with automatic home washer																												
Neutral soap	− 8.4	+11.5	+ 5.9	+12.2	+ 7.4	+ 8.2	+ 8.3	+16.5	+ 9.4	− 4.0					− 2.5	0.0	− 4.4	− 0.2	− 3.7	+ 2.2	− 5.1	+ 0.4	− 5.4	+ 2.0				
Fabric 2 (gabardine I)																												
Sonic washing																												
Neutral soap	+10.5	− 8.9	+ 1.4	−11.0	− 7.7	−16.1	− 5.5	−12.6	+ 5.4	−11.4					−11.2	− 3.7	−13.4	− 2.1	−14.6	− 3.8	−15.6	− 2.6	−16.2	− 2.7				
Built soap	+ 7.6	+ 3.0	− 7.5	− 7.4	− 7.1	−11.4	− 7.9	−11.2	− 6.8	−14.2	−18.4	−16.0	−13.3	−16.6	−10.3	− 5.2	−15.0	− 7.0	−13.2	− 9.8	−10.3	−10.2	−12.1	− 8.2	−13.4	− 7.4	−12.8	− 6.7
Washing with automatic home washer																												
Neutral soap	+ 4.6	− 7.5	− 4.2	−10.3	− 3.0	− 6.4	− 9.6	−12.4	−13.1	−19.8					− 6.2	+ 1.3	−15.6	− 1.8	−16.7	0.0	−23.1	− 2.2	−25.7	− 2.8				
Fabric 3 (poplin)																												
Sonic washing																												
Neutral soap	+ 8.0	+ 9.0	+ 2.5	−15.0	− 7.2	−11.5	+ 7.3	− 8.5	+ 5.2	− 5.5					− 9.4	− 2.9	− 9.9	− 0.6	−10.3	− 0.9	−14.4	− 2.3	−11.8	− 1.6				
Built soap	+10.1	+ 0.9	− 7.1	− 5.0	0.0	− 3.9	+ 1.0	− 5.3	− 4.3	−10.0	−16.4	− 7.6	− 8.2	−28.0	− 6.2	− 4.5	− 0.5	− 5.3	− 4.3	− 4.4	−15.0	− 7.5	−12.1	− 9.8	−12.0	− 7.6	−13.5	− 4.1
Washing with automatic home washer																												
Neutral soap	− 1.1	− 2.3	−22.0	−23.4	−33.7	−24.2	−39.8	−24.1	−34.0	−35.0					− 7.2	+ 1.4	−16.2	− 0.1	−21.3	− 1.1	−27.2	− 1.5	−26.3	− 2.1				

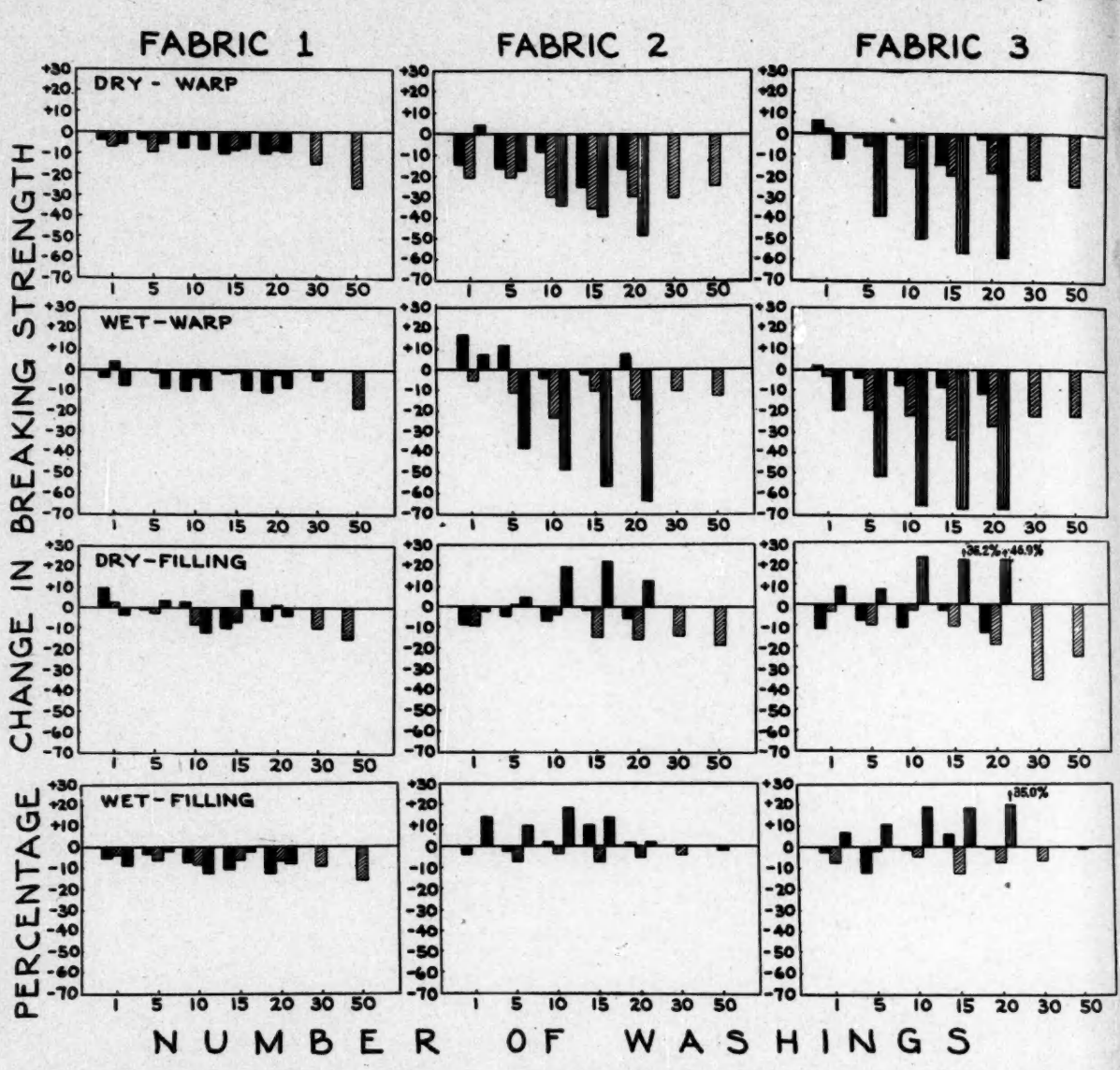

FIG. 3. *Comparative breaking-strength losses sustained by 3 fabrics washed, respectively, by the sonic and the automatic home washer under the conditions described in the text and in Table III, Part A. (Temperature, 120°F.)* ▮, *Sonic washer with neutral soap.* ////, *Sonic washer with built soap.* ||||, *Home washer with neutral soap.*

In warp dimensional change, the automatic home washing machine tended to cause more shrinkage than did the sonic washing series except in the textile fabric of firmest construction (fabric 1) when 20 washings were applied with neutral soap, and with all other conditions the same except for type of washer. Dimensional changes in the filling direction were small in comparison with warpwise changes through 20 neutral-soap washings with both types of machine.

Although after 20 washings the built-soap, sonic washing series had caused somewhat more dimensional change than had the neutral-soap series, the further changes with the built soap through 50 washings were not great.

Summary

In a study of the performance of a laboratory model of a home sonic washer, invented in Australia and described herein, the effect on the strength and dimensions of six rayon fabrics representing a wide variety of types was studied.

Comparisons were made with the results of washing by hand and with washing by means of the sonic

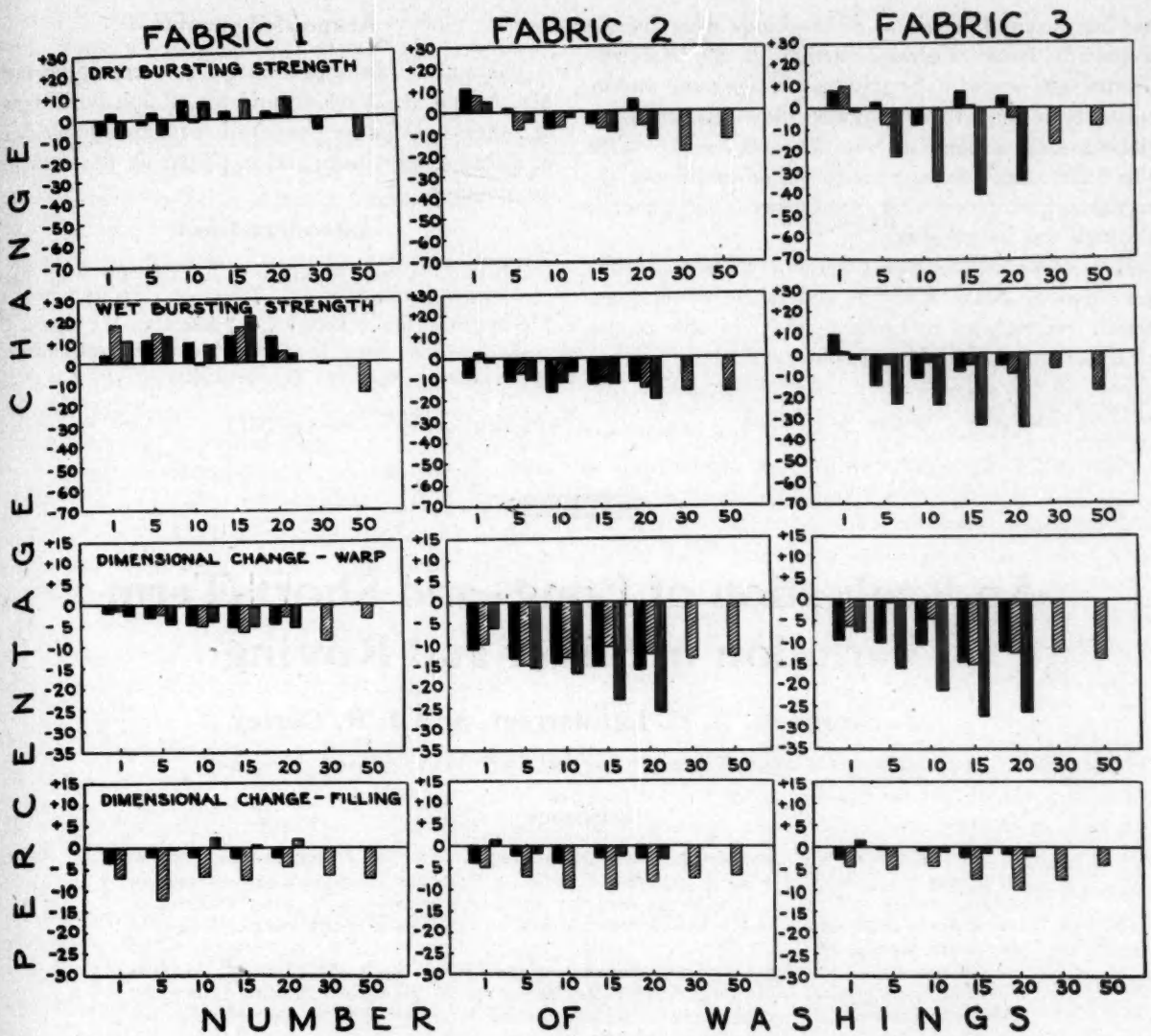

FIG. 4. *Comparative bursting-strength and dimensional changes sustained by 3 fabrics washed, respectively, by the sonic and the automatic home washer under the conditions described in the text and in Table III, Parts B and C. (Temperature, 120°F.)* ▮, *Sonic washer with neutral soap.* ////, *Sonic washer with built soap.* ||||, *Home washer with neutral soap.*

device. The results generally favored the sonic washing technique, although the hand washing was done for a shorter time per washing and at a lower temperature. Differences between the two washing techniques were greater with fabrics of lighter weight and less firm construction.

In another series of comparisons, 20 repeated launderings, using a neutral soap, were carried out with the sonic device and with a conventional automatic home washing machine in common use in this country with three of the fabrics used in the previous trials. Over-all washing time was the same in both cases. Strength losses were low and were not greatly dissimilar in the fabric of greatest strength, having a plain weave and firm construction. In the other two fabrics, however, strength losses with the sonic washer were far less than with the more conventional type of home washer. Dimensional changes, likewise, tended to be greater with the automatic home washing machine for the two fabrics of less firm construction, with little difference in the case of the heaviest, firmest fabric.

Another washing series with the sonic washer, using a built soap and 50 washings, showed generally

far less strength losses at 50 washings than did the automatic home washing machine at 20 washings. Shrinkages tended to be greater with the sonic washer using built soap than with the same washer using neutral soap through the two 20-wash series. With the built soap, however, only minor additional dimensional changes were experienced, in general, through the 50 washings.

The sonic washer used showed a marked conservation of fabric strength and fabric dimensions, which recommend a further study of the acoustical method of producing washing action. A further report on the sonic washer under investigation, including detergency results, will follow.

Acknowledgments

The authors are indebted to Dr. Frederic Bonnet, Mr. Arthur R. Wachter, and Mr. Ralph R. Riegner of American Viscose Corporation for invaluable help in planning this study and in preparing the data for presentation.

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An Evaluation of Long- and Short-Term Variation in Sliver and Roving

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Abstract

To study the effects of processing variables on product uniformity, a procedure for evaluating uniformity has been developed. Two types of variation, long- and short-term, are common in slivers, rovings, and yarns. It is shown here that short-term variation is a better indicator of the effects of processing variables than is either long-term variation or a composite of long- and short-term variation.

By measuring only short-term variation it was possible to: study the effects of doubling and drafting on product uniformity; develop drafting curves for the various drafting systems by which product variability may be predicted; and develop a formula for the comparison of the variation in unequal counts of roving and yarn.

Introduction

Variation of weight per unit length is considered the most important of yarn irregularities. It is a fundamental either upon which such properties as strength and appearance of yarn are directly dependent or by which they are greatly influenced [9]. Since much of the irregularity of yarn originates in the early stages of manufacture and is carried forward and amplified by each drafting process through spinning [5, 7], obviously it is desirable to correct product variations at or near the point of occurrence. Research organizations and industry, therefore, have devoted much time and work to studies of product uniformity in the preparatory mill [2, 7, 10].

As part of the research at the Southern Regional Research Laboratory to evaluate machine performance during drafting and doubling—as one means of obtaining a greater knowledge of product uniformity—the effects of long- and short-term variation during these processes were studied. A gradual change of weight over a number of yards of a cotton product is defined in this report as "long-term variation"; and the unevenness found within 1 yard or a shorter length of product as "short-term variation" [3, 12];

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the long-term variation, on the basis of these definitions, being a composite of short- and long-term variation. Since such a composite measurement would not have provided the precise evaluation of the effect of machine performance on product uniformity that was desired, separate measurements were obtained by using selected sample lengths on a modified standard uniformity tester.

Since even the most advanced methods reported in the literature [1, 8] for measuring and evaluating product variation are not adequate with respect to the distinct effect of the short- and the long-term variation, the simple methods used at the Southern Regional Research Laboratory, which may offer some advantages, are described here, and some of the curves obtained are presented and interpreted. The results lead to a better understanding of the fundamentals of the two variables and the influence of each on product uniformity. The results emphasize the importance of the short-term variation as an indication of variability in sliver, roving, and yarn; and demonstrate the value of drafting curves as a processing guide to secure better product uniformity.

Experimental Conditions

Uniformity Testers

A compression-type uniformity tester, the Saco-Lowell sliver tester,* converted to electrical recording [4, 11] was used to measure the uniformity of card and drawing slivers. This tester was also used to measure the uniformity of most of the rovings studied. Since the compression groove on the Saco-Lowell tester was designed to measure roving of 1.5 hank or coarser, and it was desired to test much finer rovings than that, multiple-strand uniformity testing of roving was used. The Uster tester * and single-strand strength tests were used to determine the uniformity of the yarns.

Selection of Sample Length

Sliver.—A sample length of 1 yd. was used with the converted sliver tester, and readings were taken at 1-in. intervals along the sliver axis. It was found that with a sample longer than 1 yd., the value of the short-term variation was modified by the degree of long-term variation present. This modification would occur because the long-term wave—a gradual change in weight—would cause the mean, about which the deviations are taken, to change. As a result of the changing mean, the scatter of the readings would not be a true scatter caused by short-term variation, but would be the result of two different phenomena occurring simultaneously.

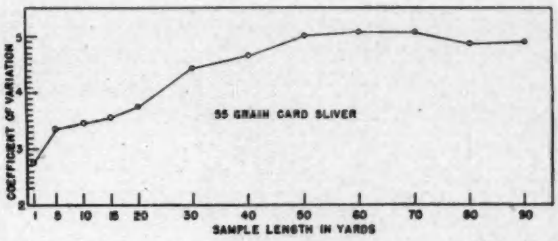

FIG. 1. *The effect of sample length on the coefficient of variation in sliver.*

Figure 1 shows the effect of sample length on the coefficient of variation. As length is increased, the coefficient of variation also increases. At approximately 60 yds. the curve begins to flatten. When the sample length is short, the value of the coefficient of variation is more nearly a measure of the short-term variation.

The degree of accuracy of the average coefficient of variation per yard depends upon the number of samples taken. For example, when 125 1-yd. samples were used, the results were found to be accurate to approximately 5%.

Roving.—The sample length required to measure short-term variation in roving must be of a length that will hold constant or eliminate the variations that have occurred in the stock prior to the roving process. It is evident that if different lengths of roving are tested, the variation will increase with each increase in length until all significant variations have been accounted for. The variation will then level off, with only an infinitesimal rise in slope. The point at which the curve levels off should be the length used for testing roving, since most of the measurable variation is accounted for at this point. Tests were made on 1-, 5-, 10-, and 20-yd. lengths, and the variations were plotted against length, with the results shown in Figure 2. Figure 3 shows the frequency for these different lengths plotted against the deviation from the mean. Here it is evident that as length was increased, the range remained the same, with only an increase in frequency. Thus, testing beyond 5 yds. contributed little to the significance of the results; hence, 5-yd. sample lengths were chosen to measure short-term variation in roving.

* The mention of trade products does not imply their endorsement by the Department of Agriculture over similar products not mentioned.

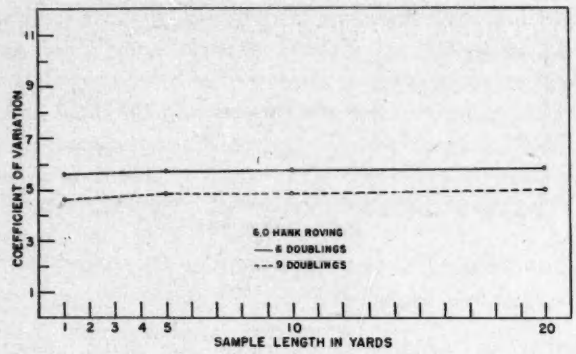

FIG. 2. *The effect of sample length on the coefficient of variation in roving.*

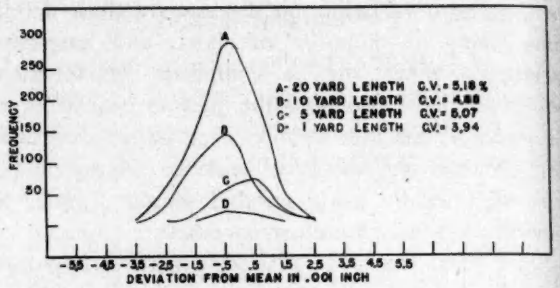

FIG. 3. *The effect of sample length on the frequency distribution for roving.*

Variation in Sliver

Long-Term Variation

Drafting and Doubling.—The long-term variation in card sliver is unaffected by successive processes of drafting, but is directly affected by doublings. To study the effect of drafting and doubling on long-term variation, a card sliver was produced using a variable-speed feed-roll drive. The long-term variation was made to be periodic; thus, a simulated long-term wave was produced in the card sliver.

Figure 4(a) illustrates the variations of this card sliver.

The long-term variation may be expressed as a numerical value by finding the coefficient of variation of the long-term curve.

One end of this sliver was fed to the drawing frame and was drafted 4 times, with the result shown in Figure 5. It can be seen that the wave length was increased and the amplitude decreased by the draft. But the mean diameter of the sliver was also decreased by the draft; thus, the coefficient of variation is the same as that in the undrafted sliver. This experiment indicated that drafting without doubling had no effect on the long-term variation. If, however, more than one end is fed to the drawing frame, as is common practice, the long-term wave is reduced by the square root of the number of ends doubled. This reduction follows the law of doublings:

$$V_R = \frac{V_o}{\sqrt{n}},$$

where V_R = the resultant variation, V_o = the variation of one end, and n = the number of doublings.

An Application of Doubling.—An application of the doubling theory was made as follows: Six ends of the experimental card sliver (Figure 4(a)) were doubled and put through a single-delivery, 5-roll drawing frame. Figure 6(a) is a graph of this first drawing sliver, which shows that when 6 ends were doubled and drafted, the periodic curve, for all practical purposes, no longer existed. To further demonstrate the effect of doubling, this first drawing sliver was compared to ordinary card sliver (Figure 4(b)) put through the same drawing frame and drafted 4 times (Figure 6(b)). It is seen that both slivers have almost identical curves.

While it is true that the long-term variation in the experimental card sliver was exaggerated, and curves of this type are not normally found in practice, it was possible, even with this exaggerated variation, to make very good first drawing sliver. Thus, small long-term fluctuations in the card sliver are relatively unimportant, as is shown by the extent to which the periodic curve in the experimental sliver was reduced by the doubling at the first drawing process.

Short-Term Variation

Drafting and Doubling.—Studies of the effect of short-term variation in sliver, in contrast to the effect of long-term variation, showed that drafting does significantly increase short-term variation, so much so that the leveling-off tendency produced by doublings is partially offset.

This effect was shown by measurements made on the sliver fed to and delivered by the drawing frame. The coefficient of variation of a sliver going to a particular frame was found to be 2.77%. After one end of this sliver was drafted 6 times on a single-delivery frame, the coefficient of variation was increased to 10.09%. If the drafting process had not changed the relative arrangement of the fibers, the coefficients of variation before and after drafting would have been approximately equal. Thus, it follows that the short-term variation that exists in

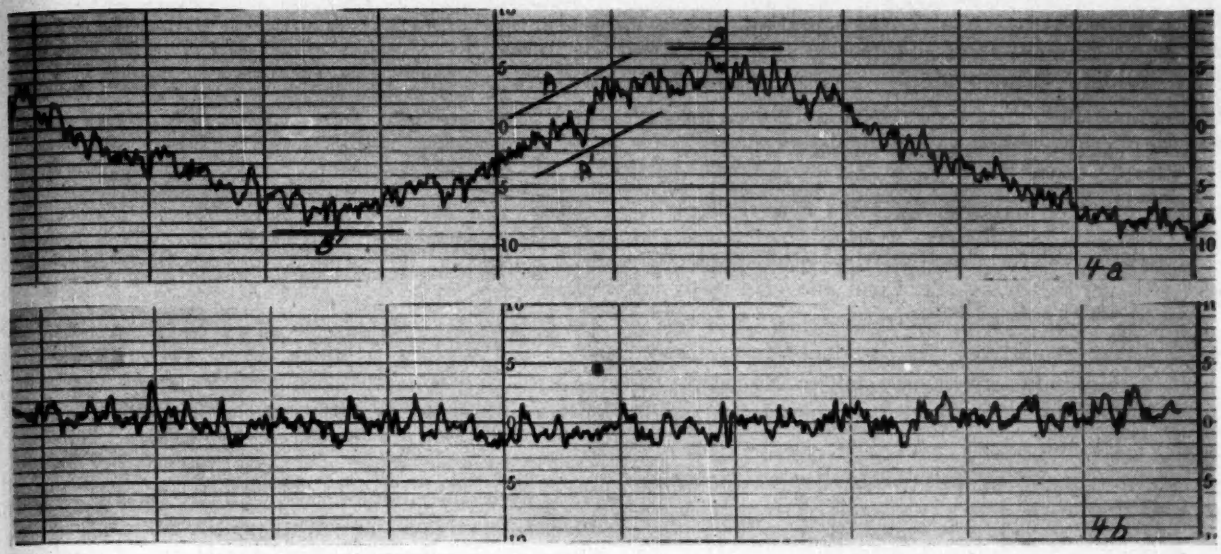

FIG. 4. a—*Card sliver in which the long-term variation is periodic, the section between* A *and* A′ *showing the short-term variation, and that between* B *and* B′ *the long-term variation.* b—*Card sliver without the periodic curve.*

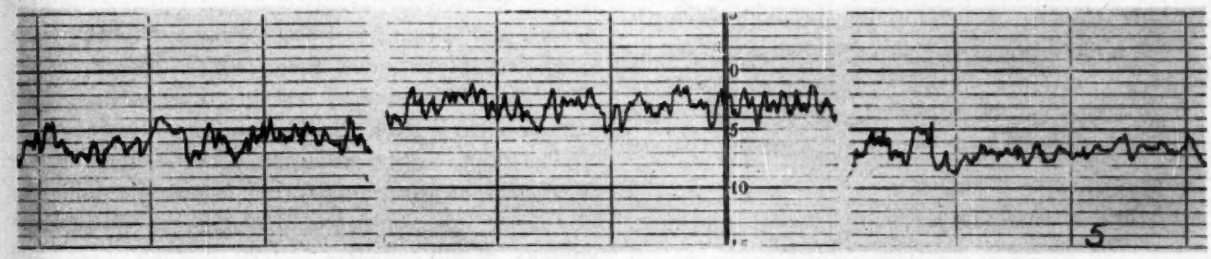

FIG. 5. *Result of drafting 4 times one end of the sliver illustrated in Figure 4*(a).

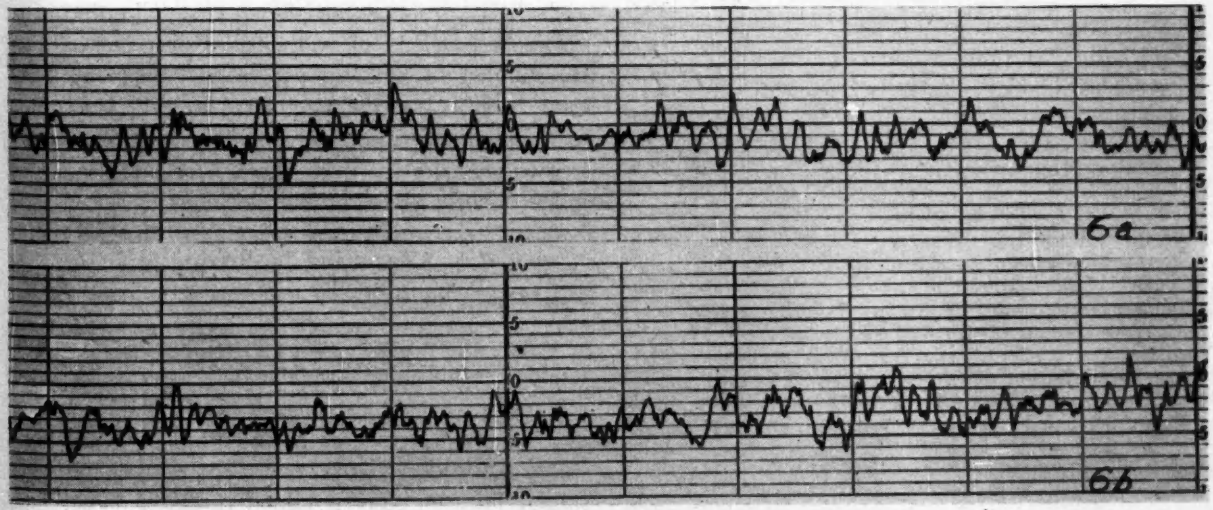

FIG. 6. a—*First drawing sliver made from card sliver illustrated in Figure 4*(a) *(6 doublings, 4 draft).* b—*First drawing sliver made from card sliver illustrated in Figure 4*(b) *(6 doublings, 4 draft).*

card sliver can never be improved in the products of the succeeding processes using existing techniques and machines. This indicates that the drawing frame is not an evening device, but rather a medium through which the law of doublings is applied.

Effect of Sliver Variation on Yarn Properties

To show that the short-term variation in sliver is not reduced in roving and yarn, and is directly responsible for much of the unevenness in yarn, lots of card sliver (A and B) were produced from a blend from a bale of known variety and processed on the same equipment under controlled atmospheric conditions. The long-term variations in the two lots showed no significant difference. But the coefficient of variation of the first drawing sliver for lot A was 4.74%, and for lot B 9.75%. Both lots of sliver were made into 3.00-hank roving, and the evenness, as measured on the Uster tester, was 11.7% for lot A, and 16.0% for lot B. The roving was spun into 25s yarn, and the yarn was tested for single-strand breaking strength, elongation, skein breaking strength, and yarn number. The data obtained are given in Table I.

It is seen that the coefficient of variation of the single-strand breaks, a very good measure [6] of yarn uniformity, was 11.90% for lot A and 16.66% for lot B. Thus, the variation in the sliver carried through the roving and into the yarn.

TABLE I. IMPORTANT PHYSICAL PROPERTIES OF COTTON YARNS PRODUCED FROM SLIVERS OF DIFFERENT VARIATIONS

	Lot A	Lot B
Single-strand strength (g.)	354.9	316.8
Standard deviation	42.24	52.77
Coefficient of variation (%)	11.90	16.66
Standard error	4.22	5.28
Elongation (%)	7.0	5.2
Standard deviation	.67	.83
Coefficient of variation (%)	9.57	12.53
Standard error	.07	.08
Skein strength (lbs.)	81.3	74.8
Standard deviation	3.93	3.64
Coefficient of variation (%)	4.83	4.87
Standard error	.80	.74
Yarn No.	23.8	24.4
Standard deviation	.29	.43
Coefficient of variation (%)	1.22	1.76
Standard error	.06	.09
Evenness		
Uster (mean deviation (%))		
Roving	11.7	16.0
Saco-Lowell (coefficient of variation (%))		
Sliver	4.74	9.75

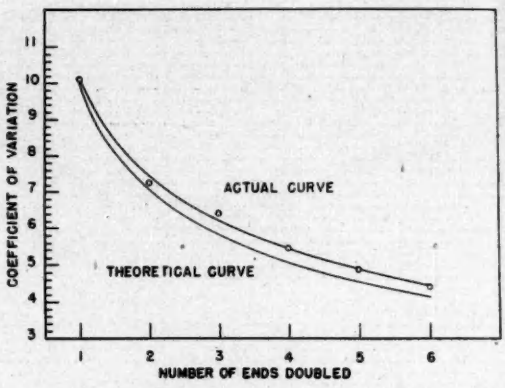

FIG. 7. *A theoretical curve compared to an actual curve showing the effect of doubling.*

That doubling does not improve drafting—that six ends cannot be drafted with any more success than one—is illustrated in Figure 7. The lower curve is the theoretical curve, based on the law of doublings and an original first drawing sliver whose coefficient of variation was 10.09%. It represents the calculated decrease in variation as this sliver was doubled 2, 3, 4, 5, and 6 times.

The upper curve is an actual curve, showing the coefficient of variation plotted against doublings as the sliver was doubled 2, 3, 4, 5, and 6 times and drawn. The coefficient of variation decreased and was governed by the same law that determined the shape of the theoretical curve as the number of ends fed was increased. If at any point the actual curve had fallen below the theoretical curve, then the number of ends represented by this point could have been drafted better than one end alone. The fact that this did not happen indicates that, regardless of the number of ends fed, each end may draft independently of the other.

Variation in Roving

Test Correction

When total draft was plotted against variation found in roving made on the 10 × 5 long-draft roving frame, using two weights of sliver (55 and 65 gr./yd.) made from the same cotton, two parabolas were obtained (Figure 8). Foster [5] obtained similar lines by plotting added variance. The equation of the parabola made from the 65-grain sliver is $Y - 5.36 = .740 \log (\text{draft} - 1)$. If the slopes of the parabolas made [3] from the 55- and the 65-

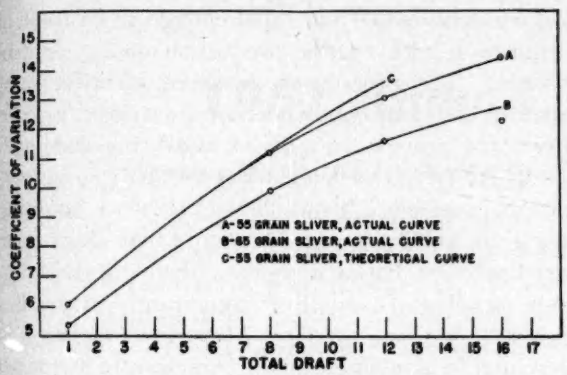
COEFFICIENT OF VARIATION
TOTAL DRAFT
A-55 GRAIN SLIVER, ACTUAL CURVE
B-65 GRAIN SLIVER, ACTUAL CURVE
C-55 GRAIN SLIVER, THEORETICAL CURVE

FIG. 8. *Total draft plotted against coefficient of variation on 10 × 5 long-draft roving frame.*

grain slivers were inversely proportional to the square roots of their weights, the equation of the parabola made from the 55-grain sliver would be $Y - 6.01 = .844 \log (\text{draft} - 1)$. The actual data followed this equation sufficiently close enough to justify the conclusion that the slopes were inversely proportional. This decrease in variation with increase in weight of sliver leads to the fundamental conception that the short-term variation of a product is due to two combined causes: the inherent variation that is due to the number of fibers per cross section and the variation of the individual fibers; and the change in arrangement of the fibers introduced by the drafting system. The general equation of the parabolas in Figure 8 is attributed to the relative rearrangement of fibers introduced by the drafting process, while the change in slope for change in weight is attributed to the number of fibers per cross section.

It follows that if two weights of sliver, roving, or yarn are processed on identical drafting systems, the heavier one will have less variation simply because it has more fibers per cross section. Thus, from Figure 8 it is seen that if a 55-grain sliver is drafted 8 times it will have a coefficient of variation of 11.20%. On the basis that the decrease in slope for increase in weight is due to the number of fibers per cross section, a 65-grain sliver drafted 8 times would have less variation than the 55-grain sliver drafted the same number of times. The variation of the 65-grain sliver at this point would be that of the 55-grain sliver proportioned inversely to the square roots of their weights; it would be $11.2 \times \frac{\sqrt{55}}{\sqrt{65}} = 10.3\%$. This checks closely with the actual variation of the 65-grain sliver drafted 8 times (Figure 8).

Thus, when the variation of two slivers, rovings, or yarns is being compared to determine the effects of processing variables, the products must be placed on an equal number of fibers per cross section basis by proportioning the variation inversely with the square roots of their weights. This can be done only if each sliver, roving, or yarn has been subjected to equal drafts. When unequal draft has been used, any conclusions must be made only after analyzing the drafting curves.

In the present work the test correction was found to be very helpful with the sliver tester used.

The square root of the average rack-pin reading, on the converted-type sliver tester [4, 11], can be substituted for square root of weight.

An application of the test correction was as follows: Two supposedly 6.00-hank rovings were run on the sliver tester. One gave a mean rack-pin reading of 36, and the other of 35. The variation in the roving with the 36 reading was 6.80%, and in that with the 35 reading 7.00%. How would these variations compare if both were placed on an equal-weight basis? Applying the law that their variations are inversely proportional to the square roots of the rack-pin readings, a coefficient of variation of 6.90% would be that for a roving of 6.80% coefficient of variation and rack-pin reading of 36 placed on the basis of a rack-pin reading of 35. Now the coefficient of variation of the two rovings can be compared.

Prediction of Product Variability

It can be seen that with drafting curves similar to those in Figure 8, and with the aid of the law of doubling, the combination of drafts and doublings that would give the most uniform end-product in the mill could be ascertained.

For example, a 55-grain sliver has a coefficient of variation of 6.01%, and a 65-grain sliver one of 5.36%. It is desired to make a 2.00-hank roving on the 10 × 5 long-draft roving frame, whose drafting curve is shown in Figure 8. Is it better to use the 55-grain sliver and draft 13.2 or the 65-grain sliver and draft 15.60? Reading from Figure 8, the 55-grain sliver drafted 13.2 would give a roving with a coefficient of variation of 13.5%; the 65-grain sliver drafted 15.60, a roving with a value of 12.5%. Therefore, it is better to use the 65-grain sliver at this process to make a 2.00-hank roving.

To obtain a drafting curve, only one weight of product fed would need to be used at each process, and the equation for this weight would be in terms of the initial variation (variation of product entering the process), the resulting variation, and the total

TABLE II. EFFECT OF ROVING VARIATION ON THE STRENGTH AND UNIFORMITY OF YARNS SPUN FROM 1.35-HANK ROVING USING $\frac{31}{32}$-IN. M.+ ROWDEN COTTON

	Lot I	Lot II	Lot III
Yarn count	9.69	9.67	9.73
Coefficient of variation (%) of roving (uniformity)	6.95	7.26	7.41
Yarn skein count strength product (lbs.)	2138.0	2131.4	2102.0
Yarn single-strand strength (g.)	917.6	911.5	902.0
Coefficient of variation (%) of single-strand strength	9.59	12.12	11.58
Coefficient of variation (%) of skein strength	3.50	4.10	5.50

draft. Equations for any weight product can be developed by differentiating the known equation, proportioning the slope thus found inversely with the square root of the weight (or of the average rack-pin reading) of the unknown, and then integrating the result.

Effect of Roving Variation on Yarn Properties

The influence of roving variation on yarn qualities was investigated as follows:

Three lots of 1.35-hank roving, each with a different coefficient of variation, were spun into 10s yarn. This yarn was tested for count and single-strand and skein strength, with the results shown in Table II.

The single-strand strength is seen to be the best indicator of the effect of roving variability on yarn quality. Both the average single-strand and skein break and the coefficient of variation between each single-strand break showed that the variation in the roving carried over into the yarn. These results indicate that more of the quality-control testing should be conducted on the products processed in the preparatory mill. By doing this, measures could be taken to correct variability nearest its source and eliminate the accumulation of variable products.

Discussion and Conclusions

It is generally agreed that variation of weight per unit length comprises two types of irregularities, identified as long- and short-term variation [3, 12]. Some progress has been made by various scientists [1, 8] in measuring each separately and evaluating the results; but it is believed that the test methods and techniques previously used in the evaluation of uniformity are too involved and time-consuming even for research purposes. The present study has contributed a method of testing and evaluating variation which is simple and rapid enough to be used in conjunction with routine production quality-control systems. The procedures described identify satisfactorily both long- and short-term variation in card sliver, and provide a means of measuring and evaluating each type of irregularity through successive stages of drafting. It was shown that stock doubling effectively levels out long-term more than short-term variation; and that as a result of doubling the long-term variation of card sliver significantly diminishes with each doubling process. Short-term variation is decreased by doublings, and is significantly increased by drafting.

Future studies may prove short-term variation to be the more detrimental of the two types of product irregularity and to be directly responsible for much of the production loss due to end breakages. Since much short-term variation in yarns is due to the variation in sliver and roving, its measurement will permit corrective measures near the source. Thus, the accumulation of nonuniform stock during the lapse of time from the origin to its disclosure by means of yarn tests would be avoided and contribute to a high level of quality.

Acknowledgments

The authors wish to express their appreciation to personnel of the Analytical and Physical and Mechanical Processing Divisions, and to acknowledge the assistance of C. L. Sens, In Charge of the Processing Section of the Cotton Mechanical Processing Division.

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1951 Annual Meeting, T. R. I.

Symposium on Impacts of Research in the Textile Industry

Because of the widespread interest in the papers delivered at the 1951 Annual Meeting of Textile Research Institute, the papers are being published in full in TEXTILE RESEARCH JOURNAL. *In the following pages of this issue are the papers given at the General Session on Friday, November 9, 1951. Those given at the Technical Session on Thursday will appear in the February issue.*

Blending of Cotton by Fineness Determination and Other Applications of Research in Mill Operation

Walter Regnery*

THERE HAS BEEN much general talk concerning the need for, and possible application of, research in the textile industry. Many of us in the textile industry have felt that research will pay off over a given period and have therefore assisted such work by supporting cooperative research organizations such as Textile Research Institute or the Institute of Textile Technology, and, in the case of the larger companies, by having our own research laboratories. However, a large segment of our industry has not given any support to research. This may be due to many reasons, but one explanation might be too much general talk and too little specific example of the usefulness of research results in everyday mill operation. I hope to show one application of the findings of research men to the operation of our mill that has been most helpful. If I can show by this one example where a research tool has been used to give big improvements in mill operation, maybe some of the nonsupporters in our industry will reexamine the benefits of lending assistance to research organizations.

One big problem confronting the research worker in textiles is to develop reliable tools to measure the degree of perfection of the product he is working with, either in the raw or in the finished state. He cannot depend on human judgment, as was done in the past, because he is seeking out much smaller differences. In the cotton industry, for example, extraordinary skill of human judgment has been developed in classifying cotton fiber as to length, grade, strength, and fineness, and in evaluating the quality of the finished yarn. The results of such judgments have been used to establish the best running conditions for our machinery, but, because of the rather rough way we evaluate our materials, we have not been able to make precise minor adjustments which can add up to give a substantial gain.

Effect of Cotton Fineness on Yarn Production

One of the machines developed by research scientists to determine accurately and quickly the fineness of the cotton fiber is the instrument known as the Micronaire. The average fineness can be estimated from the rate at which air under constant pressure passes through a weighed sample of fiber. Once this tool was available, cotton of known fineness could be processed and evaluated in terms of mill operation. It was shown that very fine fibers tended to make a stronger yarn since it had more fibers in a given cross section; however, unless these fibers had un-

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usually high individual strength, many more neps would develop from the very fine cotton. Very coarse fibers would process with few neps, but could not be used to process light yarns because there would not be enough individual fibers per cross section in the yarn to allow proper binding together of the fibers.

Window-shade cloth is made at our mill, which is a print-cloth-weight fabric of a premium quality. The high quality is dependent on producing yarn with the smallest possible number of neps and with the most uniform appearance which can be obtained from carded stock. In order to make window-shade cloth, the yarn must be woven into long cuts which have a minimum of minor defects and no major ones. We are therefore very interested in keeping our neps down to a minimum.

We believed that the fineness of cotton directly affected the number of neps in a yarn and its appearance. Spot checks on the 1950 crop showed that the fineness of cotton produced in any given area varied widely. We buy most of our cotton in the Memphis area, and tests showed that the fineness of a single crop lot would average as low as 3 μg./in., with some bales as low as 2.5 μg./in. Other lots might have an average fineness as high as 4 μg./in.

To evaluate the effect of fineness, 5-bale samples of this new cotton were run through the mill. These lots were run one after the other on the same machinery throughout; the results shown in Table I were obtained.

With an average fineness of 2.9 μg./in., a 62 nep count and 64 ends down per 1,000 spindles per hour on 30's yarn were obtained. On $1\frac{3}{32}$-in. and $1\frac{1}{8}$-in. cotton, if it were mature and strong, one could actually spin up to about 54's, or at least 50's, and be within the spinning limits. However, one very rarely finds cotton of this length which has this low fineness, so that the poor performance is due to immature or undeveloped fibers. With $1\frac{3}{32}$-in. and $1\frac{1}{8}$-in. cotton having a fineness of 4.2 μg./in., the highest practical spinning limit is 37; therefore, when spinning 30's yarn we were trying to reach only 82% of the spinning limit for this particular cotton. However, for 5.3 μg./in. in fineness, we went to 102% of our spinning limit for this particular length cotton, because the highest spinning limit that one could possibly get out of it would probably be 29's, and this would be very difficult to run. It was obvious from this mill test that we would have to be very careful in processing either very fine or very coarse cotton.

TABLE I. EFFECT OF COTTON FINENESS ON THE SPINNING OPERATION

Sample No.	Average fineness (μg./in.)	Nep count	Ends down per 1,000 spindles per hour on spinning 30's yarn
1	2.9	62	64
2	4.2	35	28
3	5.3	22	62

Our past procedure was to buy crop lots from chosen localities, with some lots containing as many as 1,000 bales. These bales were shipped to the mill and stocked in our warehouses in stacks of about 1,000 bales. When this cotton was consumed, one of these stacks was used up before another was started on. Often one stack would represent one crop lot, and this would be the feed for our mill for 2 weeks. Checks on the 1950 crop showed that the fineness of one of these lots of cotton might run as low as 3 μg./in., and when this occurred we would have our mill loaded with very fine-fibered cotton which would give excessive neps, high ends down in spinning, and other difficulties. We therefore decided to assure ourselves that the cotton going into our mill each day would have as far as possible the same average fineness. This was done by grading the baled cotton by fineness as it was received, and blending bales of the finenesses required to achieve the desired average. This procedure was followed for the entire 1950 Delta crop, and the results have been most gratifying.

Procedure for Grading Cotton by Fineness

After the purchase was made in Memphis, the samples from the bales were expressed to our mill. If the lot represented one crop, the fineness was determined on every fifth bale. If the maximum variation for a given lot were not over 0.5 μg./in., the average of these tests was used to assign a fineness to this lot of cotton. If the variation in reading were more than 0.5 μg./in., all the bales were tested, and the individual bales were assigned their own fineness. Our total purchase of this type of cotton to run into the new crop would be about 35,000 bales. By the time the cotton started arriving at the mill, we had determined the fineness on about half of it. A tabulation of these results showed that if the cotton

were segregated into fineness groups, we would be able to blend these groups in the opening room and have the proper percentage of each fineness going into the mill daily for the entire crop.

The four fineness groups set up were: (1) less than 3.2 μg./in.; (2) 3.2–3.8 μg./in.; (3) 3.8–4.2 μg./in.; (4) more than 4.2 μg./in. Knowing the fineness of a given lot or bale of cotton by the time it arrived at the mill, we would then store it in a warehouse containing only bales in one of the above fineness groups. To feed the mill, a given number of bales could be taken from each warehouse, or fineness group, so that we would have the same blend as to fineness going into the mill every day.

In Figure 1 is shown the fineness distribution of the bales of cotton purchased to run our mill for 10 months. This cotton was all very carefully selected, being bought mostly from crop lots in the Memphis area. About 95% of it came from West Memphis, Arkansas, up the river 50 miles, all in Delta land. The staple of the cotton ran from $1\frac{3}{32}$ in. to $1\frac{1}{8}$ in., and the grade was all Middling or above. The seed was about 90% D.P.L. 14 with some Stoneville 2B. The most interesting point about this graph is that this wide variety of fineness was obtained with such carefully selected cotton. It looks as though it is quite impossible to buy cotton with a narrow range of fineness by selecting either variety or territories. Since this is the case, it seems imperative to blend such cotton by fineness if we expect even running work in our mill.

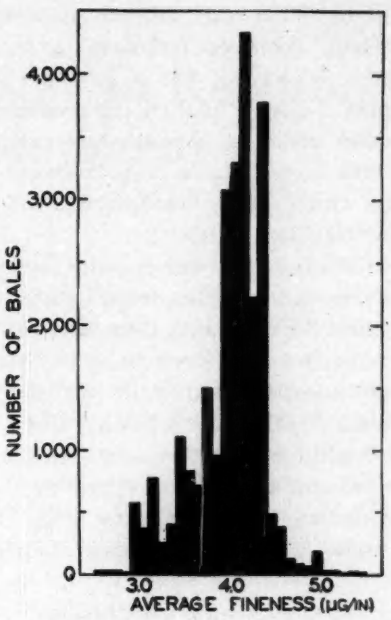

FIG. 1. *Fineness distribution of cotton bales.*

Results

Figure 2 shows the operating results from following the procedure outlined above. The lower curve represents weekly card nep counts on 100 sq. in. of web for the 1949 crop season, in which we did not blend by fineness, and for the 1950 season. The curve levels out for the time we blended by fineness, with a maximum count of 39 neps and a minimum of 35, whereas the old procedure gave variation from 25 to 54. Further, the general average is lower, even though we had a poorer crop as to nep quality in 1950 than in 1949. It goes without comment that our product was correspondingly more uniform after we blended by fineness than it was before. We also noticed little variation in ends down throughout the

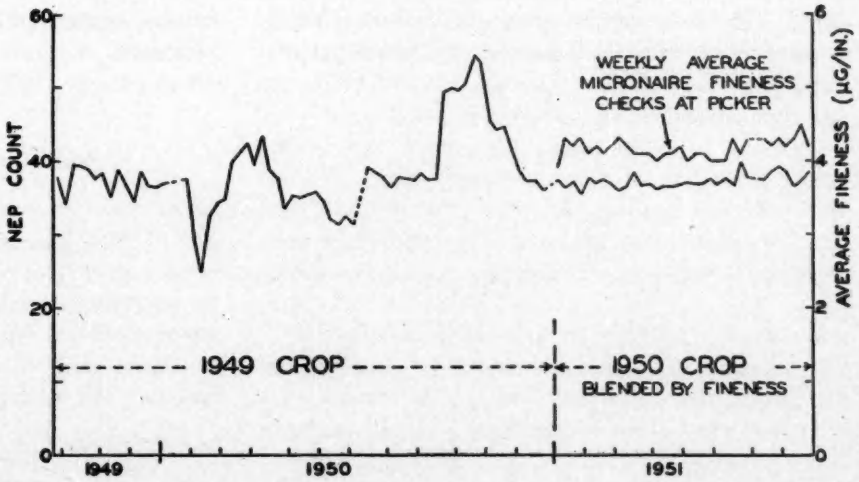

FIG. 2. *Average weekly nep count (neps per 100 sq. in. of card web; 24 cards per day).*

running of the 1950 crop, whereas in 1949 we had the proverbial "good and bad days" in the running of the work.

In Figure 2 also is plotted the average fineness determination made on samples taken daily at the picker. This curve varies only between 4.0 and 4.5 μg./in., which clearly demonstrates the effectiveness of our blending system.

Figure 3 shows one of our opening lines and indicates how the various bales were blended together. We have three such opening lines, and each was set up on this basis. The blend indicated on the diagram is the one that was set in each day, and we ran the entire 35,000 bales following this procedure.

The only additional cost to carry out the outlined procedure was for the labor of operating the Micronaire instrument. For the entire crop of 35,000 bales this came to $2,500, or seven cents per bale.

Summary and Conclusions

To summarize, we can make the following statements:

(1) The fineness of cotton strongly influences the spinning operation and the quality of yarn produced.

(2) Uniform fineness in a supply of cotton cannot be attained by buying cotton of a single variety or from a single region.

(3) By measuring the average fineness of each bale and by proper blending on standard mill equipment, one can be sure that the cotton being fed into the mill has the same average fineness from day to day.

(4) When the fineness of the cotton entering a mill is controlled in this way, variations in nep count at the card and in the finished product can be reduced. Ups and downs in the operation of spinning or card rooms can be eliminated, and spinning production can be held near maximum speed since only a small reserve must be maintained to allow for performance variation.

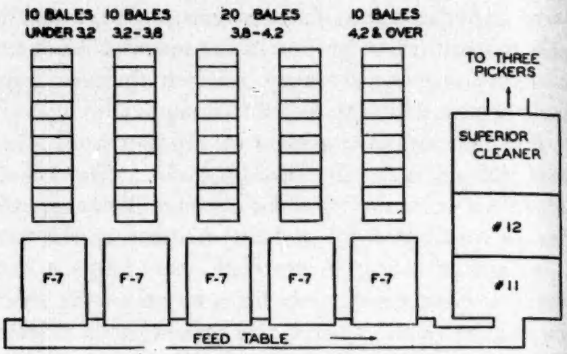

FIG. 3. *Setup for opening lines, indicating how bales of cotton are blended together.*

(5) Control of fineness permits a mill to operate its machinery continuously at the optimum settings for fibers of the fineness grade decided upon.

In conclusion, I hope to have shown where we have successfully used a tool and procedure developed in a research laboratory and applied them to our everyday mill operation. Today we produce a better product in fewer man hours because we have utilized this technique. Research, in this instance, is paying daily dividends. This is only one simple example of where work accomplished can pay off to make our textile industry more competitive. There are other similar examples where research is paying dividends which have come out of the comparatively small effort of the textile industry in this field. This limited research has proved itself to the industry. An expanded program is badly needed. If industry's support of research were doubled, I am sure that we could look to the future with much more confidence.

Position of the Textile Industry in Relation to Research and Development

Richard D. Wells*

ALTHOUGH RESEARCH has some justification solely as the satisfaction of intellectual curiosity, it flourishes best and accomplishes most when related to the technological phases of a given field. For proper reference and perspective, then, textile research should be considered against the background of the textile industry. This is considered by some of us as highly important, for we find far too many people on both sides of the picture making assumptions based on industrial experience with research in general which are not entirely valid with respect to our own situation. It is from these misconceptions that arise the frustrations of the researcher in trying to deal with our industry, and the impatience of the industry in dealing with research. The researcher feels that he is owed some appreciation; the industry, if expecting anything at all, wants nothing less than miracles. Neither is frequently forthcoming.

I shall define "textile industry" as that conglomeration of groups which starts with the unorganized fiber or filament and processes it through to finished fabric, mesh, web, or strand, ready for division and fabrication into the final usable item or unit. My reasons for using this definition will, I hope, become apparent as I proceed. I have no intention of slighting the role played by fiber producers and others; I wish only to try to clarify the relationship. I might even conclude that these auxiliary groups, rather than being considered by my definition as banned from the "brotherhood," have actually taken over the "lodge."

History of the Textile Industry

The textile industry, compared to most other major industry groups, is exceptional both in history and in organization. It is old. From a background of home craft predating every artifact except simple stone and wood shapes and crude ceramics, it originated the industrial revolution from which the other major industries were derived. We can look down from our senior position at such upstarts as motors, electric power, chemicals, plastics, electronics, and biologicals as exploiters of novelties which have yet to prove that they are here to stay. While the first chemists, for instance, were still stirring things around in pots, not knowing whether the result would be a new explosive, dye, hair tonic, or embalming fluid, and perhaps still hoping for 14-karat gold, the textile industry was turning out by the mile intricate and beautiful fabrics which even today can hardly be matched for perfection. In fact, we can go even further to say that the basic industrial achievements, such as harnessing of natural power, precision interchangeable machinery, and chemical synthesis, received their first real stimulus and exploitation by application in the textile industry.

There are reasons for our long history. It so happened that nature was kind enough to provide a fair variety of good raw materials which didn't have to be smelted, reacted, concentrated, or basically modified to render them useful. Textiles also met the very primitive needs of environmental protection, personal vanity, and early recognized requirements of modesty as society progressed to larger tribal units. Fabrics' usefulness to humanity did not have to be sold by artificial stimulus, nor wait for developing cultures to establish needs over and above requirements for primitive living. Many of us of a tough Friday afternoon dream of shucking off civilization's complications—our phones, autos, radios, and other such trappings—to take to the woods to lead the simple life. Few of us would dream of striking off for the woods, however, without our shirt, pants, tent, and blanket. This all accounts for the early start and steady growth of the textile industry, and augurs well for continuity well beyond our own times.

We must recognize that the textile industry was a highly developed art, in technology as well as in craft skill, before science had found its connection with practical matters, and long before science became a common industrial tool.

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This fact has been noted by others, sometimes with smugness, but not often enough with a full understanding of the consequences. I will dwell on this further in rebuttal to the common accusation that the textile industry was just too stodgy and stupid to take up this bright new tool of applied science and do the amazing things with it which have been accomplished in other industries. Actually, the textile industry did not pass up science—it was itself passed by.

Let's put it this way, if you will excuse the allegory: We were that older girl next door, mature and seemingly self-sufficient. Science, in its callow youth, found more interesting prospects down the street. The allure of novelty was there. Also, these cute little numbers were easier to get a line on, and were definitely "on the make." (Please don't follow this further than I intend.) That once rash youth, now established and grown up a bit, is trying to see what time he can make with the girl next door. We wonder how he will be received—certainly not as he was with the others. Flashy manners do not impress. Scientific jive talk falls on deaf ears. Glowing promises bring only cynical response. The only sure approach will be that of maturity. There must be that slow growth of understanding, appreciation of merits, acceptance of limitations, and, above all, faith that the liaison will be of real mutual benefit. This may be a bad illustration, particularly as to oversimplification, but everybody loves a romance, and there is some insight to be gained from it.

The cold, hard fact is that we were passed by, not due to our weakness, but due mainly to our strength. It was rather complimentary. It gets right down to people. That new breed, the scientist, with practical aspirations, moved towards fields other than textiles, and probably showed good personal judgment in so doing. The textile industry was a going concern, already complicated and delicately integrated. It was already down to seemingly rock-bottom costs. It was a surplus industry. It had little control over its raw materials—not a very good prospect for a bright young man out to show the world what industrial research could do. There were other factors, better discussed later under organization, which made the textile industry a singularly unrewarding, if not completely futile, field in which to delve.

That was the situation up to a generation or so ago. We were then in the peculiar position of turning out astronomical quantities of useful and occasionally beautiful materials, without ever having to know very much, in a truly scientific sense, either of our ingredients or our end-products. Fibers were accepted as nature supplied them, and the consuming public accepted the fabrics as to quality, if not always in satisfactory quantity. There was a limited range for selectivity within types, but wool was wool, cotton was cotton, linen was linen, and silk was at least partially silk. There was little thought as to what might be obtained with wholly new materials. There were no definite ideas as to the properties new materials should have to show advantages over traditional fibers; similarly, basic concepts of the real properties of the older materials were almost completely absent.

At about the time a few inquisitive souls began to get a lineup on the natural fibers, the chemical industry butted into the picture. Stirring up an evil-smelling mess of dissolved cellulose, they squirted it through holes to form something which geometrically at least resembled a textile fiber. The terminology applied is significant. Chemical science had produced "artificial silk." It was artificial all right, but it wasn't silk. Its only qualification to greatness was that it was formed as a continuous filament, a condition formerly achieved only by the patient efforts of the silkworm. The fabrics made therefrom were "slick and lustrous," to use kindly terms, compared to spun staple materials. Less kindly terms might have been more appropriate.

The cellulose-based regenerated fibers were tamed, softened, delustered, and otherwise modified to render them acceptable. They found their place as additions to, and not as alternates for, the traditional fibers. Strangely enough, one of the widest applications of these fibers was in the chopped-up state. Starting with the preformed, comparatively uniform, continuous-filament yarn, one proceeded to hack up the material and make yarn of unevenly oriented and distributed staple fibers.

Not content with that, the coal-water-and-air division began to squirt their own concoctions into filamentous forms. Not to be outdone, other divisions swiped skim milk from the hogs, corn from the cows, and peanuts from the elephants to make new textile fibers. Nothing was sacred. Even nomenclature became a problem. To the textile industry it was more confusing than amusing. And, we are told, the trend has just started.

We are, then, suddenly inundated with a flood of new fibrous materials even before we have gained true knowledge of the fibers of antiquity. How shall

all this be handled? Shall we just follow the trends, running "Plimpton" when that is in fashion and switching to "Synyarn" when that gets the nod from *Reader's Digest,* or shall we mix them all up in our hopper blends and try to satisfy everybody? This blending business reminds me of Shaw's classic reply to the beautiful lady who made the proposal to form a liaison to start a super-race, combining his brains and her looks. Perhaps we should do well to share his pessimism that the combination might equally reflect her brains and his looks.

The impact of the synthetic fibers upon the textile industry is a terrific jolt. It reveals most dramatically some of the peculiarities of our business other than those of its history. The same peculiarities are equally significant in less dramatic ways as they relate to other affairs of the industry, which brings us to the subject of the organization of the textile industry.

Organization of the Textile Industry

The oddities of organization are easier to understand if we know the history and magnitude of the industry. Although it is one of the top industries in dollar sales and employment, textile manufacturing is made up of thousands of individual plants, most of them dealing with only a part of the serial operations required to carry fiber through to finished fabric. These are sometimes linked in groups for purposes of financing, purchasing, sales, and integration, but such groups are rarely under central technical control. Many are still trying to play a lone hand, isolated in more ways than by geography alone. It was a logical distribution for the varying conditions existing throughout the industry's history. Water power was available previously only in small concentrations at scattered points. Finances were available principally within the scope of personal fortunes. Operative employees were available only as the secondary wage earners of local family groups. Later, foreign-born employees were better controlled in the smaller communities. Still later, many textile mills moved back to the country to utilize the scattered help which was available from a sliding agricultural economy.

This long-time dependence on employees from the less demanding populations is the direct result of another peculiarity. Textiles has a long and unique history as a surplus industry. This has had profound effects, not only on wages and salaries. Competition for the limited market took off all the fat and some of the lean. Surpluses were seldom available for financing bold new ventures, and risk capital was hard to wheedle from those bold barons who didn't mind a poor risk but insisted on chances of a real killing if successful. There were occasional seemingly prosperous times—a rather hollow prosperity, though, because the wage earners never did catch up to other industry standards. And there was always an overdue backlog of maintenance expenses to take care of. The roof needed patching, the floors repair, and the machinery overhauling or replacement. The whole psychology and philosophy is influenced by this surplus, low-margin aspect. It really cramps one's style.

As individual units, textile mills may seem quite impressive with their large buildings, swarms of employees, and tons of raw materials and products. However, financial return for their efforts, in terms of added market value per ton of raw material, is one of the lowest for any consumer commodity. Supervision, of necessity, is stretched pretty thin, and there is little leeway to support such fancy doodads as laboratories, pilot plants, and nonoperative specialists running around the plant.

A factor frequently overlooked by people glibly comparing the various industries is that of sheer numbers. Textiles are the product of a unique combination of intensive and extensive activity, complicated by the long array of sequential processes required to go from fiber to finished fabric. The implications are worth some consideration here. Other industries require personal skills and intricate machinery, and some a number of serial processes perhaps approaching those of fabric manufacture. None other that I know of extend these into the replication that is common to the textile industry. Consider one single product delivery unit, the cotton spindle. Juggling some averages and inverting, we find that it would take that one unit some 30 days continuous running to spin an average person's yearly consumption of cotton yarn in this country. The total job takes a lot of spindles and all the rest that goes with it.

This means that change is slow. One doesn't just insert a new tool or die, turn a few valves, or put a new ingredient in the feed to make a commercial success of a new textile idea. At some of the most critical points in textile manufacture, any change involves conversion or replacement of hundreds and thousands of units. Tampering at any one stage also generally entails compensating changes elsewhere,

and these may also be in considerable replication. It all makes experimental work difficult, and hard to exploit if successful. It means also that the experimenter is frequently working with a complex of variables almost defying differentiation, and is seldom able to pin things down to precise and duplicable measurements of cause and effect. Those who have been in the game know how frustrating that can be.

Another peculiarity is that our industry has the traditional pattern that individual enterprises are made or broken in the market place, and not in the plant. That isn't unique today on the sales end, for many other industries are approaching the same state of affairs. But both the purchasing agent and the sales agent have had dominating roles in much of textile industry history. There was a mill off in the hills somewhere grinding the stuff out. It was an almost standardized piece of equipment, a necessary nuisance, which did at least lend an air of stability and respectability. It could also be bled white, and frequently was, when market conditions were tough. Mill properties were frequently traded in the market, with about as much demonstration of proprietary interest as shown among used car dealers.

A newer trend, again minimizing the importance of the production unit itself, is that many enterprises today are being made or broken at the bargaining table. With so much standardization of process, and so little leeway in relative efficiencies, agreements on wages, work loads, disciplinary control, and so forth, are rapidly becoming the dominating factors in determining the fate of the individual enterprise.

Another factor is that of personnel. It has been said with some truth that one of the troubles with our industry is that there are only textile people in it. There is little of the free interchange of people's ideas and experiences common within many other trade groups. We live in textile towns, or as a separate caste in the few heterogeneous industrial communities having textile plants. Operating executives were traditionally the second sons of the owning families, or successful individuals who came up through the ranks and were seldom out of earshot of their whirring machines except on the annual fishing trips or at a textile convention. We draw indoctrinated recruits from our own trade schools rather than from general engineering and industrial-management institutions of learning. Our machine operators were either born and raised within the shadow of the mill, or had never seen a factory till they signed on. We are known by the lint in our ears, the harried look on our faces, the dye on our pants, and the holes in our shoes. It's a way of life as well as a trade.

We have an industry which has never had control of its raw materials except through the slow and much-tampered-with workings of supply and demand. We suffered through with the vagaries of price, types, and qualities as altered by unpredictable weather or the strange workings of man. Politics, hard-headed agricultural economics, and even social-welfare activities have all influenced the distribution, market value, and properties of our natural fibers. Even at the worst, though, there were some established trends and weather reports to go by. Now we never know who is cooking up what out in some laboratory, with a drooling copywriter outside the door, draft in hand, waiting for the cue to fill in a few identifying words and rush to press. We learn from the good wife, who saw the paper first because we had left for the mill before the paper boy arrived, the name at least of the new miracle we would be struggling with the next year. (Maybe it will have a new name by the time we get a sample to handle.) At any rate, she already wants a swatch for a dress in order to create a little diversional conversation at the next club meeting. And so does her cousin upstate, who tried the local store after reading her morning paper and, disappointed, phoned down for a swatch in that heavenly maroon to match her new felt hat. What an old sour-puss papa seems to be as he tunes up the ball game and mumbles something about streaks, embarrassing static, pale shades only, gaping seams, and ridiculous price. But the women win out. He is going to have to try to run it.

Much of our industry is at the mercy of a fickle market. Fashion is a cruel mistress. Can you imagine the auto industry stopping its lines and madly retooling in order to follow a popular demand instigated by some slick custom maker who unveiled a car at the show with leather-covered mudguards? That situation is normal to much of our business. We make those fenders or default on our debentures. Furthermore, in an equivalent way we put real leather on the big ones, leatherette on the middle ones, and a snappy simulated ostrich-grain paint job on the little ones more startling than the original. Even staples have suffered, as witness, for example, the big blow to an erstwhile stable group in our industry when one of Hollywood's exponents of male virility, doffing his shirt before

the camera, revealed his chest with no further adornment that nature provided. Market statisticians have not yet finished their computations as to how many undershirts disappeared into the missionary barrel and rag bag.

The market is rough on us in other ways. We make a deferable commodity. When the consumer feels poor or, as now, hesitant, she patches the sheets, turns the collars, dyes her gown, adjusts the hem on her coat, darns the socks, and makes do with what she has. This is not to be criticized too harshly. Thrift has still some virtue even in this crazy age. That same consumer, however, in a different mood is later stampeding to the stores and stripping the shelves and racks, though perhaps bewailing the lack of choice. She frequently buys unwisely both in quantity and quality. That's her affair. But the poor manufacturer is now hiring back his help and trying to make a nickel while he can, and hoping he can guess when to cut back again so as not to be stuck too badly with later unwanted merchandise. This gyration is actually more violent than it appears at the retail level, for there are usually at least one or two inventory levels between manufacturers' stock and retailers' shelves which as frequently act to accentuate as to compensate. What it amounts to is that in rough times, we can't sell much of anything, no matter how good it is, and in boom times we can sell about anything we want to make. This is a situation not too conducive to long-range product-development programs.

One of the most discouraging aspects of the market as it affects the technical end of the business is that our products sell or don't sell according to about every other index imaginable except: (1) true worth in an engineering sense; and (2) what the consumer would really like if given the facts and the choice. Subjective values predominate over the technical values, initial price over value, novelty over suitability, and prejudice over common sense in many portions of our business. In the latter instance, we even have the extreme case where a truly improved product is unmarketable unless at the same time it can be produced for less money. It will take just that much more promotional expense to convince the intermediate markets that it is even as good as the original. What a heartbreak for the development man who thought he had really accomplished something.

We have been dependent on stock machinery from a surprisingly small group of suppliers. These firms offer a limited selection from which to choose. Evaluation of the relative merits of alternate types can be done in most cases only by large-scale, long-term production runs. Very often the mill has had to make a commitment on faith alone, and find out later how good was its purchase. In very few cases has the textile industry itself been able to dictate the design or operating characteristics of the equipment it has to run.

We have also been highly dependent on the chemical industry for these auxiliaries to our work, even for the design of whole processes involving their use. While we don't want to appear ungrateful for the assistance given, we can now be a bit critical of the manner in which it was done, for much of that dependence was very deliberately fostered. It takes less nerve now to bring it to light, for it is beginning to be apparent that the thing has backfired. It was a smart game, but too many could learn to play it. The result is that our industry has not yet had a chance to diagnose its own symptoms and needs, while trying out all the nostrums, balms, elixirs, and soothing syrups which we are so diligently urged to try. Our drug rooms today are well named. They look like a hypochondriac's medicine cabinet.

We have been dependent in several more, less obvious ways, only one of which I will mention here. Our traditional fibers, because of their agricultural origin, have received a good portion of what attention has been paid to them from governmental agencies. Industry has relied on this work, and until lately has taken few steps either to duplicate or supplement it. It has been good work for the most part, and very well intended. As such affairs go, however, it did not take into full account all factors of significance to the processing industry. Farmers' and ranchers' interests frequently predominated. Because of their charters, such agencies naturally avoid like the plague any sign of favorable interest in the newer fibers not directly generic to plant and animal sources. The earlier reliance, though, now leaves the industry inadequately set up with facilities by which all fibers, natural and synthetic, can be studied and put through their paces to demonstrate their proper places in the textile economy.

All of the points I have discussed so far, as they relate to matters of textile research, add up to the following summary observations. The textile industry, as defined, due to history, organization, and conditions of servitude, hasn't learned to appreciate

research, is not very well set up to use research, cannot afford it in the competitive intramural way of other major industries, and is everlastingly preoccupied and bedevilled by matters that are seemingly more crucial.

It is of interest that certainly no more than a quarter of the attendance at this meeting represents the operating and technical end of the textile industry as I have defined it, and that this group is greatly outnumbered by those representing auxiliary interests. I certainly wouldn't want to indicate any lack of welcome to these other groups, but this distribution is worth a bit of thought.

Maybe the significance actually lies in the distribution of interest, maybe in the distribution of free time for personnel to travel, maybe in financial condition, or maybe just geography.

I do think it reflects in part, at least, the distribution of faith, the faith that there is something to be gained from research. It would seem, then, that there is a certain lack of optimism in the spot where it is needed most—in the textile industry itself.

That lack of faith is not without reason. It is actually the result of experience with textile research as it has been conducted so far. Except for the slow results of tinkering, major textile developments, originating for the most part from the auxiliary interests, have created more problems for the industry than they have solved. Not that I believe we should be immune from the growing pains of progress. We should expect to share with other industry groups the defeats of obsolescence, the trials of retraining and retooling, the frustrations of control of ever more finicky processes. At times we share with them the secret wish for a moratorium on developments in order to give us a few years to absorb what we've got. On the other hand, we would like to be able to share with them that sense of being masters of our own destiny. We would like to be able to feel that self-development will bring some satisfaction. There has been little of such feeling in our industry. The textile man is known for his lack of bounce and grinning enthusiasm, and the industry for its corporate apathy even towards talk of progress along scientific lines. It is a real but, I hope by now, a somewhat understandable psychology.

Needs of the Textile Industry for Research

I have chosen this negative approach, if not wisely, at least deliberately. By discounting as not pertinent to textiles much of what otherwise might be erroneously assumed from general industrial research considerations, I hoped to focus attention on two positive aspects. These two are to my mind extremely vital, and yet to my knowledge have generally been lost in the guff in discussions of textile research. Both have particular significance to textiles because of their peculiarities. Either would justify a much larger fundamental and applied research program than we yet see in prospect.

The first is primarily the one I have been leading up to—being masters of our own fate. It is going to be a bootstrap proposition, with many temptations to relax and accept the many proffered chairs. That mastery can only come from knowledge, and only research will give that knowledge. We must be able to evaluate the what, how, and why of all proposed materials, procedures, and products without going off on wild ventures on the one hand, or overlooking good bets on the other. We should be able to make up our own minds as to what course we should follow for the public's and our own best interests. We can raise the flag on the day we can lay down detailed specifications before the fiber breeders and raisers and tell them to meet them or go sell it to the Government. We can fire a salute that brave day we can tell not only the producer but the world at large that his new miracle synthetic fiber "Klipton" is a fair material for shoe laces and nothing else. We can pound the drum on the day we put our own designed equipment blueprints out for bids. We'll blare the trumpets the day we can tell the salesman to go dunk his head in his bucket of "Textrazenol x 428 Ext., Concentrated, 20% solids." We'll really "tie one on" the day we can, without a quiver in our voices, tell our immediate trade customers, "This is what we are going to make because it is good value for the consumer," and to quit their yapping and get out there and sell it.

And the encouraging part of it all is that these auxiliary groups are going to take it and like it. They will welcome the stronger reference for their own activities. Their targets will be definite and their rewards much surer if, as, and when they hit the mark. There will be some degree of order and a much sounder basis for mutual progress.

This order can come only from the strength of the industry that is in the center trying to put it all together. This strength can come only from knowledge, and that knowledge from research. It would seem, then, that it would be in the best interest of

all parties to foster this basic knowledge of the materials, tools, processes, and products of our business. The auxiliary groups, which are so well represented here, should take the long-range view and consider the textile industry as the senior partner in their own businesses, and not as a middleman, customer, or dupe to be exploited for the short term. That this senior partner needs some enlightenment we shall freely grant. If there is any keynote to this informal discussion, though, it is this: *All* partners will gain by furthering that purpose. All partners, then, should bear some responsibility for this general enlightenment.

The second vital reason for textile research, according to my view, has to do with people. Though this is more definitely a matter of internal affairs, it has considerable significance for the auxiliary groups as well, for it is a factor which must be reckoned with in all proposals for application of their ideas to the textile industry.

In a nutshell, though it may look like a bombshell in certain quarters, the matter is this: While the textile industry has a rapidly increasing amount of things to be skillful about, it has a diminishing resource of skill to muster to the task. That statement will be resented, I know, and probably misunderstood. But I will try to explain my meaning and its implications.

As we noted earlier, we had a highly developed craft and technology when the scientific approach to things first became popular. The individual and personal skills were a major factor in our operations. Even as plants were set up in new locations, there was a nucleus of experience brought in from the older centers, and local skills were developed around that pattern. Until recent years there was a terrific incentive to develop these skills. A person made good in the mills or became a wanderer or went hungry. We still have a few of the old boys who were, in effect, apprenticed in their tender years before there was any choice or judgment allowed. The textile industry then had the pick of the local talent; it took them young and kept them busy. The development of these skills had the effect that much which was imperfect could yet be made to run and, in fact, became standard. The old boys and girls took pride in their ability to master these. Very frequently their own immediate bosses never knew that a lug secretly filed off here, a strip of leather stuck in there, or a dollop of salt thrown in the bath was the difference between production success and failure. These were secrets on which their jobs depended. If one knew enough secrets, maybe one could become the boss and thus be the one from whom further secrets were hidden.

But further than that, there were the highly developed senses by which the operations were controlled. The sound of the machine, the feel of the air, and the heft of the strand were as meaningful as any gages and charts. The old boys worked by intuition fully as much as by prescribed procedures.

Now there is an aspect of textile work being considered as a job rather than as a trade. There is a much shorter duration of employment, even among those who stick with it, a restless turnover, a temporary attitude, or a diversion of interest. Some of that may be healthy from a social standpoint. But there is also low incentive—in fact, a defeatist attitude as to skills, particularly in those many situations where seniority alone governs employment. We can damn the trends or we can praise them, according to our own philosophical views, but we cannot deny them. If we are smart, we shall compensate for them. This is going to take a tremendous amount of research *and* development. It goes far beyond the replacement of shifter bars with push buttons, and of eyes, ears, and hands with gages, controls, and charts. It gets down to standardization of basic stock and/or analysis of stock from which standard adjustments in processing may be predirected. It means perfection of basic machine design and complete standardization of all replicate units performing the same function. It means some very basic and smart engineering of delicate dynamic forces and balances. It means a major revolution in industrial management and control.

None of these improvements will be satisfactorily accomplished by mere dabblings. Few, if any, will be accomplished by auxiliary interests and turned over to the operating textile industry as complete packages all set with green and red control buttons. There are just two many factors for the specific specialists to account for as they tackle individual segments of the basic problem. Instrument makers can show us how to measure certain properties, but they cannot tell us what properties we should be measuring, their relative importance, or what to do once we have recorded the measurements. Chemists can work out beautifully balanced processes assuming uniformity of material, but they fail us when confronted with the variables with which we contend. Management specialists can tell us how to organize

along the ideal lines, but they are baffled as to how to get from our present setup to a better one without erasing present investment and staff and starting all over again. It is a bootstrap proposition for the industry itself. First, there must be the frank appraisal and acknowledgment that craft skills, while perhaps a desirable human aspect to foster, are not to be relied on as the predominating control factor in a surplus industry with less than average wages for a given level of skill. Second, the deliberate, positive, and enlightened program must be carried out to reorganize on a predominately automatic basis. Anybody who has yet dared to approach the industry's problems in that manner has been immediately struck by the prevalence of opinion as compared to provable and duplicable fact. There is a tremendous job for research to do—to dig up the principles by which textile processes may be automatically governed. It is strange to think of in that way, but we have got to be smarter than we have been in order to hold our own.

Beyond these two special needs of the textile industry for research, we of course have the usual objectives of cost reduction and invention of startling new products. With our operatives beginning to get into a decent income bracket, and fibers of all sorts getting to be luxury items, we are going to have to whittle away some more at manufacturing costs or else face a markedly restricted market volume. We will also probably have to run faster in the general "rat race" of competition for the consumer's dollar, bringing along innovations (and, who knows, possibly even improvements) frequently enough to tease the public into buying the new and consigning the old to the rag bag.

Three of these main objectives, and at least part of the fourth, are industry problems even more than they are individual-enterprise problems. Some of it will, of course, be done by the individual concerns, but few, if any, will have the backing, scope, or faith to undertake the more basic assignments. They probably won't be done by the Government, and little will be done by the schools, at least until they find that their graduates must have that sort of training to get by in the industry. A good deal of it may be done abroad, although I question if we really want to assume that secondary position.

The great bulk of it will have to be done by cooperative, group-sponsored, association activities. These must have the best brains that can be mustered to the task. They must have the intelligent, long-view, sympathetic, and whole-hearted support of all affected groups. Without those, we can look forward to a dismal future as that big guy with the strong back and the weak mind, the victim in all his dealings, and the despair of friends and relations.

Technical Problems of the Textile Industry

Kenneth R. Fox*

I HAVE BEEN ASKED to develop any ideas I might have about the technical problems facing the textile industry. There certainly is no argument that such problems exist, not only in our industry. but in any industry. We live in a world of technology; all we need do is look around to see it everywhere. Within our own life span we have seen the development of such amazing things as radio, television, diesel locomotives, sulfa drugs, penicillin, computing machines, 100 octane gasoline, atomic energy, and supersonic speeds—the list could go on almost indefinitely.

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Growth of the Textile Industry

Reflecting on the textile industry, there have been tremendous strides in the area of technological developments. Centuries ago the textile industry was confined to the hearth. The man of the family pro-

vided the natural fibers from the animals and the crops which he raised on the land. Cotton was picked, wool was sheared, flax was reaped, and together the family spun the yarns and wove the fabrics from which they made their clothes. In those days the requirements for the home textile industry were some land, a wife, and some children.

From this very simple beginning, the production of textiles emerged as an industry, first in the "cottage system" and then eventually in small factories. With time, companies grew larger and larger, until today there are many units which measure their annual output in terms of tens of millions of dollars, if not hundreds of millions. These plant expansions meant that the problems, hardly recognized before, became much more predominant. The emergence of integrated companies has presented problems previously unknown. As recently as 25 years ago, many of the functions of the textile industry were separate. Since that time most weavers of fabrics have found it economical to pick up their production with the acquisition of the fiber or yarn and carry it through to the finished fabric. Some have gone even further, and carry it to the manufacture of garments. A mill manager found he had to engage specialists in such fields as finance, accounting, engineering, and the like, in addition to the conventional manufacturing fields.

During this whole process of evolution, technology had a significant role to play. Hand power had to be replaced with water power, and water power in turn by electrical power; your guess is as good as mine what the next source of energy will be. Some think it will be atomic power, yet, according to Dr. Conant of Harvard, solar energy is the coming field. Textile machines were improved, replacing nonautomatic equipment with semiautomatic or fully automatic machines. Conveyor systems were introduced to simplify materials handling. New and improved fibers have entered the scene, textile chemicals have been vastly improved, and an industry which once was characterized as being run by "rule of thumb" has disappeared. Textile technology is now the important foundation on which a modern textile mill is built.

Handling Technical Problems

This brief discussion of the growth of the textile industry emphasizes how much more complex, how much more diversified, and how much more technical the textile industry has become. This brings us to what I consider the $64 question—namely, "How can we best cope with the technical problems that face us today?"

First and foremost, in my opinion, is the attitude that management must assume in facing the issue. A half-hearted, lackadaisical, "catch-as-catch-can" policy is doomed to failure. Management must adopt an intelligent, sympathetic, and aggressive approach, and, at the risk of being accused of playing on words, *management must recognize the problem of the technical problem.* There is no single, simple formula that can be applied to solve technical problems; there is no card index file that will yield the answers today or, even worse, yesterday; there is no sorting and tabulating machine that will crank out the answers. The only solution is to tackle the issue and set up a practical, realistic program that stands the best chance of producing the desired end-result. It is here that I feel many companies make a serious mistake. They have this philosophy: "How much can we afford to invest in the solving of a particular technical problem?" and "How much can we afford to gamble; win, place, or show?" I submit that this mental attitude is wrong and too short-sighted. Let me illustrate my contention. Management decides to purchase a building site, build a mill, equip it, and staff it with the best personnel available. This decision is based on the assumption that the investment involved will pay off in profits. Eventually the mill starts up, and its operation is charged out as expense. Included in this expense would be a sizeable sum for insurance. No businessman would be without it. The important point I want to stress is that insurance is looked upon as an expense, not as an investment. Management must look upon budget allotments for technical problems as expense items—not as investment gambles that fluctuate with business, but, rather, as legitimate, long-range charges that would be included in the cost of product produced. Such an attitude will guarantee that technical problems will be recognized and, equally as important, be given steady and consistent attention.

André Blumenthal, Vice-President of Sidney Blumenthal and Company, in an address concerning research expenditures given at the 1947 Annual Meeting of Textile Research Institute, emphasized this point: "Research, like all other items of expense in industry, is paid from funds obtained from the sale of merchandise. The total amount spent each year

for research must therefore bear some relation to sales. Too commonly, however, the amount for research budgeted annually is set on the basis of budgeted sales in American industry. Although research must pay for itself and must be related to the sales dollar, it is my contention that this is an extremely poor basis for determining the amount of the research budget and I shall attempt to suggest a different line of reasoning. Annual sales are bound to show wide fluctuations. Research programs must be relatively even and expenses for research will often very properly vary inversely with sales. The relation between the sales dollar and the research dollar must therefore not be a rigid one."

Mr. Blumenthal continually speaks of the cost of research as an expense, not an investment; it is a legitimate charge for doing business, not a luxury that speculators alone can afford.

There is another very important and fundamental point that management must acknowledge. That consists in defining the goal. This should be set forth in simple, concise, and understandable policies that can be understood by the technical man. Too frequently the answers given by technical groups to management are criticized because there is lack of understanding of what is being sought. This situation brings to mind a story that illustrates the point. A certain man who had utter disregard for professional men in general, and dentists in particular, was plagued with a throbbing toothache. He resisted going to a dentist because he felt dentists were a bunch of quacks. Finally, in desperation, a friend of his talked him into seeing his dentist, and our unhappy friend climbed into the dentist's chair. He opened his mouth, the dentist took a look, raised an eyebrow, and asked, "Now, my good man, which tooth is bothering you?" Our patient, in disgust, assured that his skepticism toward dentists was well founded, exclaimed, "Why should I tell you? You've got the education, you find the trouble!" The technical man is no better off than the dentist if management does not take the lead and spell out the problem that must be solved.

There has been a great deal of time and effort wasted in improper or untimely research, and a moderate distrust on the part of the nontechnical man is entirely warranted with respect to the type of research which consists simply of mixing things up or measuring something without any very clear idea as to the goal.

One way of overcoming this waste of time and money is to make sure that management has in its group someone who is able to provide high-quality leadership and to translate company objectives into language that is understood by the laboratory people. This requires a very careful assignment of liaison to assure two-way traffic unimpeded by road blocks of misunderstanding. The idea is unfortunately prevalent that one may buy a research or technical laboratory ready-made from the scientific instrument makers, and, by hiring a doctorate graduate and turning him loose, be securely embarked on a program of research which is bound to produce results. The trouble with that scheme is that there is everything present but the program and the mature and experienced brains to guide it. There is not the slightest question but that well directed and intelligent research pays well in any field in which there are important problems to be solved.

I have stressed the importance of management relaying its objectives in language the technical man can understand. This point is also valid when applied in reverse. Admittedly, technical men must use a language that is specific when dealing with one another, but there are times when technical jargon is a handicap. A technical man might say, "If we could plasticize this fiber, reduce its crystallinity, and drop its modulus of elasticity, then we could obtain a unit better adapted to energy absorption at low loads." It would have been much simpler and more easily understood if the technical man had said, "Let's soften the fiber so it will stretch more easily." Yes, there is a two-way obligation to guarantee a minimum of misunderstanding in defining objectives and relaying back technical findings.

Technical men must also be given adequate tools with which to work. This involves space, the necessary equipment, and competent personnel. The first two of these can be bought with dollars. The third ingredient, personnel, involves much more. Some men claim that technical men are a bunch of prima donnas and need special handling. I'm the first one to admit that there are some scientists who have their heads in the clouds and both feet firmly planted in mid-air. I don't feel, however, that such types are confined to technical men alone, or perhaps I should say I didn't know there were that many technical men in Washington. Seriously, though, technical groups are as average as any other group, but I don't feel they have always been treated as such.

Shortage of Technical Personnel

Securing the proper technical personnel today is a real problem which I think can be illustrated best by a few facts and figures. Industry will get barely a quarter of the 90,000 new engineers it needs this year, and the situation will be even more acute during the next 3 years. The number of engineering graduates is down to 38,000 from last year's record of 52,000, and by 1954 the number will be only 12,000, despite increased demands from government and industry. Including scientists as well as engineers, the 1951 class was down from 75,000 in 1950 to 46,800 in 1951; this figure will drop to 28,800 in 1954, of which 12,000 will be engineers. Even worse, if present draft policies prevail, only 6,000 new engineers and scientists may be available in 1954. In contrast, Russia is estimated to be training young scientists and engineers at the rate of about 100,000 a year. Because of the enrollment shrinkage in colleges, 60,000 freshmen would have to enter engineering schools in order to assure today's demand for 30,000. This is about 10% of male high school graduates, yet only 5% normally go on to technical colleges. The last 10 years show that industrial research and development have increased nearly 500%, and government research even more, yet the number of scientists and engineers in this country has barely doubled.

The textile industry is in the unique position of having a number of very excellent textile colleges from which it can draw many of its technical personnel. Having been associated with this type of education for 10 years, I readily admit some prejudice, but, on the other hand, I believe I am in a position to know at least a few facts. Currently, the textile colleges have approximately 3,000 students, and they graduated about 800 this year. The demand for these men far exceeded the supply, and it has been estimated that four times this number could have been employed. I contend that these men are exceptionally desirable to the textile industry. They have been well trained in subjects dealing directly with textiles, and in addition are well grounded in basic engineering and scientific subjects. It is from this group that many textile mills have obtained technical personnel to help advance our combined knowledge of textile technology. I submit that these colleges not only warrant and deserve the fine support and encouragement they are receiving from the industry, but also that this assistance should be increased.

Selecting the Right Fiber

I have touched on the attitude that I feel management must assume in tackling the technical problems of the textile industry and also the required tools in terms of assets, both physical and man power. Next, I should like to consider some of the current technical problems. It would be impossible to attempt to give complete coverage of the technical field in this paper. Many of our problems aren't even recognized, let alone defined. Consequently, I should like to take a broad question which involves many problems and attempt to give it broad treatment. We have all been hearing a great deal about the new fibers and their properties and uses. The question I should like to pose might be phrased, "What fiber should we use?" The broad answer would be, "Whatever fiber or fibers will produce the end-use properties desired, at the right price."

Time was when there were only three significant fibers to contend with: cotton, wool, and silk. Man-made fibers made their appearance around the turn of the century, and by 1925 cotton represented 86.6% of all the textiles used in the United States, wool accounted for 9.9%, and silk represented 1.9%. Man-made fibers at that time were virtually unknown, and accounted for only 1.6%. It was a relatively simple matter to pick the right fiber in those days as there weren't too many to choose from. Let's jump ahead to the time when the first truly synthetic fiber, nylon, came into the picture, and look at the distribution. By this time the rayons (acetate, viscose, and cuprammonium) accounted for roughly 10% of the fibers used; cotton was still at the top, slightly above 80%; wool was approximately 9%; and silk slightly under 1%. The family of fibers had increased to six grown members, and a new offspring had been born. The problem of picking the right fiber for the job was already quite complex.

It was at about this time that we began to hear of multifiber mills rather than cotton or woolen or rayon mills. New techniques and equipment were developed so that it was possible for a mill to use a wide range of fiber deniers, staple lengths, and wool qualities. We began to hear of wool and rayon being run on the cotton system, rayon and cotton blended with wool on the woolen system, and several fibers

being blended on the worsted system. Combinations of systems were employed, and the American system had its beginning. A number of companies were beginning to experiment seriously with tow, an approach which today seems to have many very interesting possibilities. The question of which fiber should be used was seldom limited by equipment, and mills were becoming capable of handling variously defined fiber lengths which an old college professor of mine described as being any fiber with two ends. It was more nearly a matter of which fiber imparted the property desired, not which fiber the equipment would handle. *Flexibility was, and still is, the order of the day.*

I'm sure many of you remember the headaches we had in learning how to handle nylon. New techniques had to be developed for throwing; weaving, knitting, and braiding requirements had to be worked out; new dyeing and finishing processes had to be evolved. Yet, these were all accomplished in a relatively few years, and the fiber is handled in a more or less routine way today. This reservoir of knowledge was the result of many carefully thought-out research and development projects. No single agency was responsible, but rather it was the combined efforts of fiber producer, yarn and fabric manufacturer, dyeing and finishing organizations, as well as merchandising and marketing agencies. The point I wish to stress is that this new fiber achieved successful acceptance through a coordinated and combined research effort involving a complete study of its properties as well as the necessary equipment and processes to handle it.

Last year synthetic fibers constituted 21% of the fibers used, cotton 68%, and wool 9%—and the family of fibers was still growing. The newer fibers on the horizon, such as Orlon, Dacron, Dynel, Vicara, and Acrilan, are now going through their preliminary investigations. Many problems have yet to be worked out before these fibers can assume a better, established place in the family of basic textile raw materials. When these fibers are more fully characterized and their attributes as well as their deficiencies known, then, and only then, will we know which fiber will meet the requirements of the fabrics' end-use.

Some textile men have wondered just which fiber or fibers would win out in the race for universal acceptance. I do not feel it is a question of which fiber will fall by the wayside, but rather which fiber will be most versatile. There never was and never will be an all-purpose fiber, in the same way that there is no all-purpose metal. Aluminum, steel, copper, and lead all have a place, and so it is with fibers. In one type of fabric, high strength and low stretch may be desired, whereas in another, high stretch and a minimum strength may be all that are required. Many other hypothetical requirements can be established, and it will be very obvious that no one fiber can possess all the characteristics propounded. As additional fibers become available with unique and desirable properties, they will be used wherever they can do the best job.

Dr. Mees of the Eastman Kodak Company, who spoke at the American Chemical Society's Annual Meeting in New York this past September, stated that we are facing a shortage of fibers rather than a surplus. Improving the standards of living all over the world will present enormous demands upon the capacities of production. Certainly, if he is correct in his assumption, we need not worry about having too many fibers, either in variety or quantity. The problem is, and always will be, one of selecting the right fiber for the right job.

Conclusion

In conclusion, I should like to recommend that all of us—management, technical worker, merchandiser—re-examine our attitude toward the technical problems facing the textile industry today. These will not be solved for us. We must be sure to recognize that this type of problem exists, and then plan our programs accordingly. This means we must provide clear and intelligent direction, adequate financial commitments to handle these problems, unobstructed channels for flow of information between management and the laboratory, trained and capable personnel as well as satisfactory working conditions and equipment, and, most important of all, a determination to tackle the job and see to it that we in the textile industry are not technical parasites, but rather can and will stand on our feet in solving our problems of technology.

There is real need for a coordinated approach on our technical problems, and the state of business in the textile industry these past several months demonstrates that the patient desperately needs injections of technology. New ideas and new products constitute one way of reviving the industry and keeping it healthy. Let's all do something about it—now!

Research Pays Off

Russell B. Newton*

TEN YEARS AGO the theme of this paper might have been "Does Textile Research Pay Off?" but today we know that it not only pays off, but it pays off often. It pays off every day of every year. As I think back on the mistakes I have made in my career, I feel gratified to realize that one of the right things I did was to encourage and help foster research in Dan River Mills, and to stand alongside it against the disinterest and opposition which greeted it in its earlier days. Who was it who said, "What is mind? No matter. What is matter? Never mind." Chemical research is proof of mind over matter.

When a textile scientist embarks on research into fields unknown or untried, who knows but that a gusher may pour forth from his bubbling test-tube? Who knows but that by some miracle may he be the alchemist who tosses the basest of metals into a seething cauldron and discovers that he has achieved the fulfillment of man's dream since time immemorial? He has made gold!

I shall draw a parallel, if I may, between the labors of the workers in two noble sciences, chemical research and astronomy. Each worker explores the unknown, ever seeking what he knows not, yet hailing it when he finds it. One peers through the immediate intimacy of a magnifying lens to give a measurable size to a microscopic particle. The other sweeps the heavens with a telescope to bring into intimate view an unseen giant star millions of light-years distant. The chemist seeks to make a mountain, not of a large molehill, but of the minutest granule, to observe it effloresce, and to see it burst into flower under the glass of the microscope. The astronomer must contract the magnitude of a celestial body to the comparatively tiny speck of a 200-in. lens. Each ventures into the hitherto unexplored, never knowing in what uncharted sea will he make port in a haven of discovery. Discouragement is often the lot of each, despair his bedfellow, and hope his beacon.

When the chemist has achieved the triumph of a new discovery, he is able to employ it as a stepping stone to the next relevant problem, and, although his ultimate goal may be far removed from the scene, his path has been made smoother and more directional. He will attempt to achieve the full measure of the exploration, one short step after another, rather than by the employment of seven-league boots to reach journey's end in one giant's leap. And when the researcher discovers he has strayed from the path of the Q. E. D., he must retreat only to the nearest surveyed signpost, rather than each time making a fresh start from the beginning. In the Pacific theater during World War II the validity of this principle justified itself in what was popularly termed "island hopping."

But there is no "planet hopping" for the astronomer. He cannot return to the crossroads of the sun's planets, which he has already fixed in his telescope, to take an onward step in the vastness of the Milky Way. His task is to turn back the clock, by light-years, whereas the chemist moves with time, ever onward. One aspires to see the world in a grain of sand, the other to make finite a world without end. Notwithstanding the wonders of modern photography, a fellow astronomer must journey to the mountaintop of Palomar to view a newly discovered star, whereas the disclosure of the chemist's findings may be published for all to review and the formula made available for use by other research workers throughout the entire world.

We of Dan River have long been committed to the integral place of chemical research in our operation. The inscription cut on our keystone reads "Good enough is not good enough," and we subscribe to a precept that no matter how gratifying our accomplishments, they are indicative merely of a promise of greater goals to be reached. We do not let well enough alone. Our research staff is as one family, each member working for the good of all, all working for the benefit of each, and always a willingness to set aside one's own chore to lend a helping hand to a fellow worker.

However, Dan River is not a chemical company per se, but rather a modern textile mill which avails itself of the miracles of research and applied chem-

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istry to improve the established and to discover the new. Our end-goal is to give higher styling, greater comfort, longer wear, to create a fabric suited to a specific use, and to increase with newer beauties, finer textures, and more excellences the purchasing power of the consumer's dollar.

As I look back on the results which we have achieved in the field of chemistry and envision the promises of what even the immediate future holds, I cannot say in full complacency, "We planned it that way."

Before the '40's little research had actually been done in the field of textiles by the industry itself, in comparison with the endeavors of the giant chemical companies and of the far-flung commercial organizations in other industries. Up to that time much of the research which was being attempted in textile companies was the work of men in mill production organizations, through their own inclinations and aptitudes, rather than by managerial dictum or because of established precedent. In Dan River there were several men in the plants who possessed native talent for research and experimentation. However, their efforts sprang from their own impulses rather than from impetus sparked by executive policy.

The efforts of these trail blazers must not go unnoticed or unheralded. The activities of these men were confined within informal and inadequately equipped laboratories scattered throughout the plants and tucked away into dark corners, and there was no coordinated effort made to bring the results of their industry into the light or to make them pay off.

Taking no credit to myself, the realization made itself manifest that the talents and the value of these men lay in research, and that their time and their abilities might be employed more profitably if they were taken off their production jobs and supplied with the necessary equipment and facilities to enable them to engage efficiently in ordered research. With this in view, several small laboratories were installed in one of our old mills which at that time was being used for storage. We were most fortunate that we made the choice of our own Dr. Chase, recognized as the dean of Southern dyers and a pioneer researcher in the chemistry of dyeing and finishing, to head the venture.

A little later, there was another addition to the budding program of chemical research in the person of a top-flight, imaginative mechanic. He was handed a few tools with which to fashion needed equipment. The fledgling group proceeded on the basis that it could look for support and subsidy only as it justified its existence.

As a starting point, and as a first project, the team started devising a procedure and a technique for manufacturing high-tensile-strength, low-stretch cotton yarns. There was a real need for yarns of this type for many industrial uses, and an immediate demand for parachute-webbing yarns.

Resin formulations were developed by our chemists which would stabilize the contiguity of the fibers with relation to each other, and a machine was designed to stretch the yarn while it was wet and pliable; while still in that state, the yarn was processed through a heated chamber, and was baked, cured, set, polymerized, hardened, and fixed into a position of permanent stability. That was fiber-bonded yarn.

Several additional programs of research were initiated in the field of resins. These were of vital import because they began to teach us something about the molecular structure of resins, about their characteristics and their applications, and also about the processing of these indispensible products and their peculiar properties of permanent adhesion. This was the forerunner of the Wrinkl-Shed achievement.

These were further exemplifications of the belief that much of Dan River's future must, of necessity, depend on a chemical approach to textiles to augment the practices set down by historical mill procedure.

The group grew very slowly, but grow it did. We added a specialist in his own specific field, a physicist for another phase, a chemical engineer to bridge the gap between theory and practice, an engineer to devise the machinery we needed, and a patent attorney. Dan River research was on the march!

It was brought home to us by then that if chemistry were to assume an important place in our industry and were to justify its cost, we would have to depend on many of our own creations and not in too great a measure on the contributions by others, welcome though these always are.

I consider it timely and appropriate to make open declaration of the tremendous mental stimulus and the great degree of help given to us by our good friends in the chemical and machinery industries, and by those in man-made fibers, yarns, and dyes, as well as by those in the newer field of electronics.

Dan River's Wrinkl-Shed is a direct "pay-off" for labors in our research program. Without research, we would not have Wrinkl-Shed. Without Wrinkl-Shed, we would not hold the place in the industry which we now occupy. As I look at a Wrinkl-

Shed fabric, with its property of recovery from wrinkling, with its resistance to dirt and soiling (meaning that before Wrinkl-Shed a garment was usually worn only one day, but now it can be worn three or four, resulting in less work for the housewife and longer life to the garment), with its ease of washing and ironing, with the fact that it requires no starching, with the fact that it holds shrinkage to a minimum and that a garment will not shrink out of fit, with the fact that it resists mildew, and with the fact that it retards perspiration odor, I wonder that it took so long to develop it. Memories of discouragements and disappointments, of following many wrong trails, of fruitless experimentation and research, overcoming one obstacle and another, are dimmed, like pain, by time, but they were very real to us when we lived through them, knowing that the rewards, if we achieved the end-results, would more than justify the travail.

Bear in mind that from 1882 we were a cotton mill. We would take the cotton as the farmer grew it, and would weave the fabrics from the fiber in much the same way (notwithstanding all the developments in machinery throughout the years) and produce traditional cotton textiles. Then came Wrinkl-Shed. Although we still start with cotton, we produce something new, something different, something better—a new fiber, with new virtues and new characteristics—and women call us blessed. That is why I say that research has paid off—not only for Dan River, but also for the cutter, the wholesaler, the dealer, and, most important of all, for the housewife.

What had started as a modest venture has come to command the realization of the necessity of scientific procedure in the creation and development of all our textiles. The first step is research; the final step, when we test a finished fabric, is research. Today, our research people start with an end-goal in view, and then devise a procedure for achieving the result. Following the development of a theorem, the laboratory chemists experiment until they are able to synthesize the desired molecule in a test-tube. When the result has been achieved, the engineering chemists devise procedures and, if necessary, equipment for manufacturing the product. The final step, that of physical application, is then worked out in the pilot plant, and the project is pronounced completed. A finished fabric is added to the line, giving the sales department a new item, and affording our customer increased value of her purchasing dollar.

What is the Dan River pilot plant? One might answer that it is the large Dan River mill in miniature, its floor space spreading 100 acres, housing a family of 12,000 workers. Within the pilot plant's own confines and facilities the raw fiber is put through every phase of processing and manufacturing through to the finished fabric. The pilot plant can accomplish within a matter of hours what would take a mill many days in the routine of manufacturing. It can retrace its steps at any stage of the controlled process and initiate a different method or procedure anywhere along the line. It not only answers the query "Can it be done?" but it actually proves its case and does the job.

Chemical companies constantly bring new products to us or come to us to try out new ideas—a fiber for one purpose, a new development in dyes, or a radical departure in the employment of resinous compounds. They bring these to us to assay, to test, to put to practical application. They know they are always welcome at Dan River. Our greeting is, "What's new?"

We have explored many phases of experimentation with rayon, acetate, nylon, and the newer Orlon, Dacron, Acrilan, Dynel, and Vicara, as well as other man-created fibers. We work not only with these latest creations, but also with them in combination with other synthetic and natural fibers. I can give assurance that we shall continue along these lines with greater and more determined effort. We are depending on groups like Textile Research Institute; we take the information which they give us and scrupulously apply it on our own procedures.

One day it is a new idea, a new fiber, a new finish, a new hand, a new water-repellent. We put the job through the various processes up through the finishing of the goods, having incorporated the new factor, and even then we do not pronounce the job completed. We actually have the fabric cut and sewn as finished garments, so that, no matter what the laboratory analysis tells us, we get a comparative and irrefutable answer after the ordeal of actual, rigorous wear. This gives the assurance that when a development bears the Dan River seal, it is good and will do its job, and the customer will be happy with it.

It is apparent that the end-product must be born of a collaboration of many crafts and skills—stylists, fashionwise, patternwise, and colorwise; dyers and finishers; as well as creators of specific fibers, and experts in their application and use, alone or in

combination, in spinning and in weaving. Research must be recognized to constitute more than abstract intangibles in the creation of finished fabrics. One man dreams of design and color; another ponders a chemical formula.

Projects are initiated not only from the thinking of these groups, but also by our market contact people in New York and other style centers here and abroad. Their function is not to follow a trend, but rather to create it or sometimes to anticipate it and to adapt it to our markets and our needs. They describe to research a surface, a texture, or a desirable characteristic, and a battery of designers, chemists, and plant technicians go to work on the problem and never let up on it until they come out with an end-result. Their motto is not unlike that of our own Coast Guard: "Go out and stay out until the job is finished."

Because the entire operation is housed together, quicker evaluation of the results of a formula is possible than could be achieved by one of the great chemical houses, and quicker evaluation of a new synthetic yarn than is possible for a fiber-manufacturing company. It is but a short step from the pilot light burning in the chemist's cubicle to the waiting machinery in the pilot plant.

Let us go back to the pilot plant again. A new fabric has been conceived; it is treated for wrinkle-resistance and wrinkle-recovery; the dyes are applied; and a sample run is processed through the pilot plant. One who is uninitiated might sigh, "That's done." But this happens to be much too important a new fabric to be sent off unheralded, so the head of research takes it to New York and proudly exhibits his latest creation. But perhaps the achievement is so radical, so unusual, so far removed from the traditional and the generally accepted that, instead of being hailed with hosannas, he is met with bleak stares. Criticisms are often valid. Difficulties that are readily apparent to the man whose task it is to sell the goods might not have presented themselves to a laboratory scientist. Talk follows talk, each side presenting its case and perhaps assailing the other's, and there are suggestions and counter-proposals. From the talking and conferring and thinking may come the one added factor which will transform this fledgling into a lusty giant in one short season. Management may be tempted to take sides, but must refrain lest it impose the burden of a lot of yardage on the sales people, who maintain they cannot sell it. But management must be wary lest research grows to feel that its initiations and imaginative efforts are not sufficiently recognized or properly adjudged and adopts a "What's the use?" attitude.

Our research program is divided into two general classifications: short-term, practical research; and long-view, theoretical "don't know where it will lead" research. One experiment may take only a few days, another several months, still another years. In order to maintain control, progress must be constantly measured at regular intervals, sometimes from day to day. Yesterday or tomorrow, aggressive patience is waiting for results.

Dan River is aware that it cannot afford to relax or follow routine procedure in manufacturing technique, regardless of how traditional the fabric or the universality of its acceptance. Emerson once said, "Perpetual modernness is the measure of merit in every work." There is a never-ending demand for newer and better fabrics, and there is always alert competition ready to snatch away leadership from those who have made themselves vulnerable by resting on their laurels. The goal ever before us is that each new product must surpass its predecessors by higher styling, longer wear, greater value, or, to achieve the sublime, by all three of these.

One might ask, "What does all this add up to?" The question we eternally ask ourselves is, "How can we give the woman (women buy more than 90% of all textile consumer products) more value for her purchasing dollar?" The answer is ever before us—through research and development. It is no accident that those corporations which today hold positions of leadership in their industries have for years set aside an appreciable portion of their volume dollar for research.

Realizing from our past experiences that research is essential to the advancement of the textile industry, the question might be put, "How should it be administered and what relationship should it bear to the production activities of the company?" Any corporation which is able to finance scientific research is, without question, giving the consumer a good product at a competitive price, and occupies firmly a place of leadership in its field. It is keenly cognizant of the importance of ever improving its wares so that there will be a continuing demand for them. There should be a correlation between production and research; one should contribute to the

other. Production provides for the current success of the company, while research will insure its growth and future prosperity.

And now, as additional proof that research pays off, I am taking this opportunity to announce a new chemical discovery by Dan River research which the laboratory staff has called "X-2." This new process will afford greater opportunities in the application of the most widely used of all the man-made fibers, viscose rayon.

X-2 extends both the flat abrasive strength and the flex life of viscose far beyond accepted standards; this means greatly increased wear-life. Positive shrinkage control and the elimination of progressive shrinkage are provided. X-2 possesses the added requisite of wrinkle-resistance to any predetermined degree.

The benefits resulting from this application to the viscose fiber are permanent because the fiber molecular structure is altered. Once the conversion has been made, the altered fiber cannot return to its original state.

There are other merits of X-2: it is resistant to alkaline and acid bleaches used by commercial launderies; it will not cause yellowing of white goods; there is no problem of odor; stretching, like shrinking, is completely controlled.

The variations in desired hand or finish are endless. The goods can be as crisp or as soft as the trade may require.

X-2 is not a resin, but it can be applied on standard equipment already in use by rayon finishing plants.

It is no longer in the laboratory. It is out of the pilot plant. Dan River will offer several ranges of staple and fancy all-viscose fabrics for general sale in 1952.

We at Dan River believe that X-2, with its manifold commercial implications, should not be limited to one mill. Therefore, it is our intention to make it available to the industry at the earliest possible date. The development of this process has been the labor of years; the telling of the story has been a matter of minutes.

Research pays off. It is my considered belief that this newest product of science, X-2, will pay off not only to Dan River, but also to many other firms in the textile industry.

Building Our National Scientific Capital to Yield Applied Research Interest for Industry in the Future

Alan T. Waterman*

ONE of the nation's large textile manufacturing companies recently estimated that during a century of operations it has woven more than seven billion yards of cloth—enough to wind around the earth 160 times. This vivid bit of statistical information illustrates in a graphic way the extent of the never-ending demand for textiles.

It is particularly gratifying to the National Science Foundation, whose primary concern is the support of basic research and education in the natural sciences, to note the emphasis which Textile Research Institute gives to these fundamental matters. Our

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two organizations have much in common. Even as the National Science Foundation is a pioneering agency of the Federal Government in support of pure research, as contrasted with applied research, so Textile Research Institute is a pioneer group in stressing the importance of research to the textile industry.

It is no reflection on the progressive industry of the present to comment that research has not always had the appreciation and support that it enjoys today. Professor David B. Hertz † of Columbia University, for example, sees as somewhat typical of the industry of yesterday a comment made by a textile industrialist in the 1890's to the effect "that he thought that the electrical industry was rapidly becoming standardized and getting to the point where new research and experiments were hardly necessary. . . ."

As evidence of the rapidly changing attitude toward research, Hertz calls attention to the estimated sixteen million dollars spent on research by the textile industry in 1946 as compared with less than half that amount in 1940. However, he points out that, even so, the industry is spending less than "ten cents for research for every $100 added to the value of goods in the process of manufacture, compared with some sixty-four cents per $100 value added by manufacturing industries as a whole." If these figures offer a valid basis for comparison, it would thus appear that the possibilities for expansion of research are by no means exhausted, and there is still much that lies ahead.

The textile industry stands in a somewhat peculiar relationship to technological progress. It is undoubtedly one of the oldest and most basic of human industries. The manufacture of linen, wool, silk, and cotton from natural fibers goes back into the earliest records of human history.

In a remarkable volume * published more than 100 years ago, the scholarly James Yates brought together innumerable references in the writings of the ancients to contemporary uses of textiles: Ezekial, in his vision of the temple (Ezekial 44: 17, 18), described the priests as being garbed in turban and drawers of linen. Virgil in the "Aeneid" referred to "Thin muslin . . . with its sea-green folds," and Plato in the "Dialogues" defined weaving as the art which provides woolen garments as a defense against cold. Galen recommended silk thread for tying blood vessels in surgical operations, and Herodotus related that "the Phoenicians furnished Xerxes with ropes of flax for constructing his bridge." Thus, the earliest accounts of mankind's activities illustrate the variety and ingenuity of the uses to which textiles and fibers have been put.

And yet, until the eighteenth century, methods of spinning and weaving represented only minor improvements over those which had been employed thousands of years ago. The manufacture of cloth has been so closely linked to the basic economy of the times that innovations toward improvement were regarded with suspicion, as tending to undermine a principal source of livelihood. The "Encyclopaedia Britannica" records, for example, that when a loom was set up at Danzig in 1661, with the alleged capability of weaving four or six webs at a time without human aid, it was suppressed by the authorities in Poland, and the inventor was strangled or drowned.

Textile manufacture has long been a source of keen economic rivalry and competition. The Chinese jealously guarded the secret of the silkworm for centuries. England discouraged the manufacture of textiles in America lest the colonies develop competition to the manufacturers of the mother country. As always happens, however, attempts to stem the tide of progress were unsuccessful; and, with the invention of the spinning frame by Arkwright in 1769, the power loom by Cartwright in 1775, and the cotton gin by Eli Whitney in 1794, textile manufacture was swept along in the flood tide of the industrial revolution. Curiously enough, however, when the basic steps had been taken and the industry had become more or less stabilized, there was no strong body of accompanying research and development effort such as grew up in other fields. As Hertz puts it: "There have been improvements in both spinning and weaving, of course, but none to compare with those in other fields. As recently as 1940, research personnel in the natural-fiber textile field was numbered in the hundreds, and this in an industry providing a basic requirement for modern man. Except in the development of artificial fibers, a field which is definitely chemical, the availability of all types of scientific knowledge and a course of research in other fields has had little effect on the methods of manufacturing yarns, cloth and clothing."

† "The Theory and Practice of Industrial Research," New York, McGraw-Hill, 1950.

* *Textrinum Antiquorum*, An Account of the Art of Weaving Among the Ancients," London, Taylor and Waldon, 1843.

One of the industrial phenomena of modern times is, of course, the production of man-made fibers. The physicist Robert Hooke discussed the possibility of making artificial silk in his book "Micrographia," published in 1664, but two centuries of experimentation in Europe elapsed before a practical method of producing synthetic fibers was invented by Count de Chardonnet. Except for these rather tentative beginnings, the story of synthetic fibers is essentially that of the last quarter-century, beginning with the production of rayon by Du Pont, and by American Viscose in the mid-twenties.*

In addition to nylon and rayon, a whole new order of fabrics has grown up, including Dacron, Dynel, Acrilan, Orlon, Vicara, and others. A recent release by the Du Pont Company quoted the manager of the planning section of its rayon division, Mr. Ellwood F. Altmaier, as saying that the use of man-made fabrics totaled 1,500,000,000 lbs. in the United States by last year, a growth which had accumulated since 1910. The *New York Times* of Nov. 5, 1951, reported the Southern Association of Science and Industry as predicting an increase of 600,000,000 lbs. in the annual production of synthetic fibers in the next 10 years.

Despite the tremendous growth of the synthetic fiber industry, however, it appears that man-made fabrics have thus far supplemented, rather than replaced, natural fibers. For, while the supply has continued to grow, so also has the demand, and many of the new fabrics have characteristics especially suitable for the requirements of modern technology. As Mr. Altmaier so aptly expressed it: "Neither the sheep, the silkworm, nor the cotton plant was mentally prepared to meet the textile specifications for the fabric necessary to safely land jet-propelled aircraft."

When one takes into consideration the whole economic complex, involving not only the special requirements of modern technology but also the constantly changing situation in world markets and fluctuating supplies of raw materials, it seems safe to conclude, in a general way at least, that the world will be ready to consume for a long time to come all of the available supplies of natural and synthetic fabrics.

Thinking of these two great branches of the textile industry in terms of their evolution, one could perhaps say that the manufacture of textiles from natural fibers is the product of art and invention, whereas the manufacture of synthetic fibers is purely and simply the product of the research laboratory. The pioneering work done by the Du Pont Company in this field arose originally out of their knowledge of cellulose chemistry, growing out of their work on smokeless powder. It would be difficult to find a more perfect illustration of the way in which a whole new industry can arise, like the genie from the lamp, out of the test tube of the laboratory. It also illustrates the unpredictable nature and the unexpected by-products of research, since Du Pont's work on smokeless powder was obviously not undertaken with any thought in mind that it might lead to the establishment of a new and entirely dissimilar industry.

While the synthetic fiber industry has been climbing to such vast proportions, some very interesting research has been going on in the natural fiber field. The result has been that there have now been added to the natural beauty and durability of linen, cotton, silk, and wool such added qualities as crease-resistance, moth- and mildew-resistance, colorfastness, sanforization, and so on. There seems to be growing research-consciousness in the textile field, as reflected in the number and variety of items reported in the daily press. Last summer, for example, the Veterans Administration announced an award to a Texas chemist who developed a process that prevents wool blankets from shrinking while being washed. In August, 1951, a government agronomist in California was honored by his home community for his work in breeding a cotton plant with a longer staple and stronger fiber.

The military services have sponsored a good deal of interesting research looking toward the development of protective clothing adapted to a variety of climatic conditions, ranging all the way from the arctic to the fungus-infested regions of the subtropics. Thus, there is plenty of evidence that there is, and has been, a good deal of effective research in the textile industry as a whole. On the surface of it, it might appear difficult to make a case for the need for more research.

But it must be remembered that there are two kinds of research: basic research, which we have defined simply as the search for new knowledge; and applied research, which takes the new knowledge thus acquired and adapts it for the solution of a variety of problems of a military or industrial nature. Industrial research, of which there is such a substan-

* Orlon: Case History of a New Fiber, *Fortune*, Oct. 1950, p. 107.

tial volume in this country, tends to be largely applied research or what may be called "directed basic research."

Basic research, of which there is a much smaller volume, is carried on largely in universities and other nonprofit institutions. The steps in the entire process from the discovery of some fundamental bit of new knowledge to its application to a specific problem, perhaps years later, are not always clear-cut and well defined so that they may be conveniently labeled and clearly demonstrated; but we do know that progress in science is dependent upon the continued generation of new ideas.

It is a matter of particular interest to the National Science Foundation that Textile Research Institute should stress the importance of fundamental research and education in the sciences. On every side we see remarkable evidence of American ingenuity, particularly in the areas of applied research and technology. What is much less evident is that much of the technology of today is the result of basic research done in the past. But, whereas in the past, research and invention acted upon each other in a mutually stimulating way, with the degree of interdependence not too clearly defined, the complexity of today's technology depends to an increasing extent upon advances in theoretical knowledge. What we once left to chance, therefore, must now be planned for and adequately supported.

If we define "basic research" as merely the search for new knowledge, without immediate reference to practical aims or objectives, it becomes somewhat difficult to justify in terms of budgetary support. On the other hand, such research alone does not, and cannot, pay its own way and must therefore enjoy effective sponsorship.

At times this conception is as difficult to "sell" to the practical businessman as it is to the practical congressman. Yet somehow the idea must be sold in both instances, or we may some day be faced with a critical shortage in new ideas.

As I understand, one of the unique contributions of the Institute is the training of full-fledged Ph.D.'s in science with specialized knowledge in the field of textiles. This method of training provides to the industry men of broad theoretical, as well as specialized, knowledge who supplement the textile technologists being produced by various technical schools in the country. The support and interest of the industry enjoyed by the Institute is ample evidence of the fact that it is no longer so difficult to demonstrate to the progressive American businessman of today that the long-haired scientist has special knowledge with very practical applications for his business.

In the seventeenth and eighteenth centuries, many of the scientists who laid the foundations of modern experimental science as we know it today were men of wealth and leisure who could pursue their studies without economic considerations, while others were poor men who enjoyed the support of a patron.

Later, when the universities began to attract some of the great scientific scholars of their day, the university itself became the traditional patron and sponsor of research. So long as the universities were able to train young scientists in adequate numbers and provide means for supporting a sound body of basic research, the system was admirably suited to our cultural and economic needs. But in recent years the heavy demands of military research and development have required a larger and larger share of the research and development man power and facilities, and the universities have found it increasingly difficult to find the means for supporting pure research. This has been especially true since the Government has asked the universities to take on many contracts for war research.

It is therefore logical that there should be recognition at the national level of the importance to our entire country of basic research, and some provision made for its continued encouragement and support. The National Science Foundation Act of 1950 was passed to accomplish such a purpose, and since last April we have been staffing our organization and making plans to carry out the broad objectives of the Act: "to promote the progress of science; to advance the national health, prosperity and welfare; to secure the national defense. . . ."

Last week the President signed an appropriation bill which provides $3,500,000 for these purposes. Since this amount represents a material reduction in the $14,000,000 originally recommended by the President for the Foundation's first year of operations, our program for fiscal year 1952 has had to be scaled down and adjusted accordingly. $1,500,000 will be allocated for the support of basic research in biology, medicine, mathematics, physical sciences, and engineering. About $1,350,000 will be allocated for education in the sciences, principally through predoctoral and postdoctoral fellowships. Aside from the small amount required for the operating expenses of the Foundation, the remainder will be devoted to the development of a national policy for the promotion

of basic research and education in the sciences, and for the solution of a variety of problems related to the publication and dissemination of scientific information. The Foundation will also support the National Scientific Register now established in the Office of Education.

Although these amounts are small in relation to the approximately three billion dollars which it is estimated will be spent for research and development in the United States in 1952, and in relation to the more than a billion and a half dollars in estimated government expenditures for these purposes, we are confident that the accomplishments of our program will be high in comparison to the level of expenditures. The funds which we have available for the purpose will make it possible for the Foundation to offer support and encouragement to competent investigators with interesting projects who might not otherwise be able to accomplish their objectives.

Part of the basic research problem grows out of the changes in the nature of research brought about by the demands of today. The increasingly large requirements for research directed toward the solution of specific problems has tended to reduce commensurately the man power, facilities, and funds available for general-purpose research. Dr. Conant makes the distinction between what he calls "programmatic research," as contrasted with that of the "uncommitted investigator." The Department of Defense is now the largest consumer, so to speak, of "programmatic" research and development, and the large number of contracts for military research and development have had an impact not only upon the large industrial laboratories, but also upon a number of universities with adequate facilities for such purposes.

There has also been a change in research methods resulting from the vastly more complicated and efficient tools which research in other fields makes available. The operation of an atomic pile or of a multimillion-volt x-ray machine becomes a special project in itself, requiring the trained skills of whole teams of investigators and closely scheduled experimentation. These various trends, necessary or useful, as the case may be, are nevertheless threatening the survival of the "lone investigator" as a creative thinker.

The universities where such individuals are normally to be found have special economic problems of their own that make it difficult in many cases for them to support promising investigators to do pure research with no curricular responsibilities except perhaps the training of a few promising graduate students. The demands of defense and other governmental programs have made demands upon teaching staffs which result in added curricular and administrative burdens for remaining staff members.

But, although we feel that the Government has definite responsibilities towards basic research and education in the sciences, I am sure you will agree that industry, also, has an important interest in the matter and will not wish to leave the entire burden of support to the Government. Industry has frankly acknowledged the importance of new ideas to its continued growth and progress. At the same time, it has preferred to direct its own research and development efforts more specifically in the fields of applied research and occasionally in directed basic research. Industry is interested also in the continuous production of highly qualified, trained scientists. A number of industrial concerns have adopted the practice of offering scholarships and fellowships in the basic sciences. This practice not only increases the supply of trained man power, but makes possible the support of some basic research while advanced training is being acquired. Such a trend is a welcome one, and one which the Foundation would like to see continued and encouraged. In supporting basic research, however, industry should constantly remind itself that basic research is basic only if it is left untagged and undesignated. When it becomes directed toward the accomplishment of a special objective in a specific field, it loses its identity with the increase of new knowledge and adds instead to the already impressive volume of applied research. It is important to realize this distinction, since directed basic research undertaken to solve a research bottleneck tends to be less objective.

It is obvious, I believe, that all of us—government, industry, and universities—have an interest in, and a responsibility for, insuring the continuance of basic research and providing for education in the natural sciences.

Before leaving the fascinating subject of textile research, I should like to mention a different sort of basic research that is going on in your field, which perhaps may fill in the early chapters of the textile story.

A few blocks from the Foundation headquarters in Washington, the Textile Museum is reconstructing the story of textiles from their earliest beginnings. The curator of the museum, Miss Louisa Bellinger, is bringing to bear on this most ancient of

arts the techniques of modern scientific analysis. The museum, which represents the private collection of Mr. George Hewitt Myers of Washington, contains a remarkable collection of tapestries, rugs, garments, and textile fragments from the Near and Middle East, dating back to the first century, and from ancient Peru.

Although most of the textiles discovered in the East have been found in Egypt, where the dry climate favored their preservation, Miss Bellinger has uncovered much evidence that many of the specimens actually originated in Greece, Rome, Arabia, and other areas in the Mediterranean world. Her studies of the countries to which the various natural fibers were indigenous, as well as the S-spun and Z-spun techniques peculiar to different peoples, has thrown entirely new light on some of the history of the ancient world. She also finds that much of interest can be learned from the dyeing and weaving techniques of the ancients, which achieved results of great beauty, originality, and durability.

A recent article on Orlon * commented that "The mixed fabric trend is only beginning." This statement would sound very odd to the people at the Textile Museum, whose analyses have brought to light innumerable samples of mixed-fabric weaving, including cashmere and silk, linen and wool, linen and cotton, silk and wool, and so on. Some interesting facts have come to light regarding the superior survival qualities of some fabrics over others; in the case of a particular tapestry, for example, the woolen portions have survived where the linen have not.

One also finds that many of our modern trade practices are not nearly so new as might be supposed. There are many fine examples of linen garments made by the Arabians and fully identified in beautiful silk embroidery, of which the following inscription is typical: "In the name of God, the Merciful, the Compassionate. Blessing from God to the servant of God, Ahmed, . . . Commander of the Faithful. May God strengthen him. What has been made at Alexandria, year 262." As the Christian world reckons time, this would be the year 875 A.D.—an indication that trade labels go back that far at least.

Modern science is playing an interesting role in further unlocking the secrets of the past. I understand that the museum staff has enjoyed the interest and cooperation of the experimental laboratories of the National Institute of Cleaners and Dyers in Silver Spring, Maryland, which has made many helpful suggestions as to appropriate methods of cleansing the ancient fabrics. Surprisingly enough, with special care the fabrics will withstand washing without disintegrating.

If anyone should raise the familiar question as to the practical value of such studies, I can only reply that these, too, are a type of basic research devoted to adding to the store of man's knowledge. The museum is dedicated to the preservation and study of certain types of non-European art and handicraft. On the other hand, its doors are open to those who would share the knowledge it has discovered, not all of which is theoretical or historical. During the war, the Navy requested and received specific factual information as to why a certain type of fabric was proving to be completely unsatisfactory in the hot, moist climate of the South Pacific. I am sure that the museum staff would welcome the interest and inquiries of the members of the Institute in any situation where the accumulated knowledge of ancient skills might shed new light on some of the problems of today.

The realms of the practical and the realms of the theoretical and abstract are not far separated in either time or space. We cannot very well compare the merits of one against the other, since one is complementary to the other and both are essential to the national welfare. At the present time, circumstances have conspired to bring about an extraordinarily large emphasis on applied science and technology. At such a time it seems in order to unite our efforts in working for the preservation and expansion of basic research and to insure full opportunity for education and advanced study in the natural sciences.

* Orlon: Case History of a New Fiber, *Fortune*, Oct. 1950, p. 107.